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INITIAL KH **DATE** 11-15-04

Document ID:EDF-5153
Revision ID:0
Effective Date:09/30/04

Engineering Design File

PROJECT NO. 23833

OU 7-13/14 In Situ Grouting Project Hydraulic Excavator and Drill-Injection Rig

Idaho National Engineering and Environmental Laboratory

Form 412.14
10/9/2003
Rev. 05

EDF No.: 5153 EDF Rev. No.: 0 Project File No.: 23833

1.	Title:	OU 7-13/14 In Situ Grouting Project Hydraulic Excavator and Drill-Injection Rig
2.	Index Codes:	Building/Type WMF-700 Subsurface Disposal Area SSC ID N/A Site Area Radioactive Waste Management Complex
3.	NPH Performance Category:	______ or ☒ N/A
4.	EDF Safety Category:	______ or ☒ N/A SCC Safety Category: Consumer Grade or ☒ N/A

5. **Purpose:** This engineering design file (EDF) provides conceptual design information for the hydraulic excavator and drilling/grout injection rig for in situ grouting (ISG) of select areas of the Subsurface Disposal Area (SDA) at the Idaho National Engineering and Environmental Laboratory's Radioactive Waste Management Complex for the Operable Unit 7-13/14 Phase 2 ISG Project.

Scope: This EDF prepares alternative conceptual designs for a grout injection drill rig and hydraulic excavator for Phase II ISG of selected areas of the SDA, and selects a baseline conceptual alternative for purposes of enabling follow-on preparation by others of the following:

- A conceptual design cost estimate for project documentation
- A hazards analysis for project documentation
- An environmental assessment for project documentation
- A procurement Performance Statement of Work for inclusion in a future performance-based Request for Proposal.

Conclusions: The approach for injection grouting of contaminant waste zones for the formation of monolithic grouted masses using a roto-percussion, rotary sonic drill, or rotary drill with fluted bit and injection grouting rig attached to a sufficiently large hydraulic excavator, as depicted in Alternative 1, is considered a valid approach and commercially practicable. Standards development for hydraulic excavators is mature and covered under earth moving equipment of the International Standards Organization. The jet grouting industry is considered mature, however, standards and regulatory environment development for jet grouting equipment is immature and follows the lead of the European standards development community. Vendor knowledge, trade secrets, and expert consultant help appear to be used to a great extent. Potential future procurements for jet grouting equipment should recognize the immature status of the standards and regulatory environment of the jet grouting industry and address relevant issues in the procurement.

Alternative 2 is also considered technically and commercially practical and may provide benefits of increased production because of reduced number of repetitive operational steps, and reduction in potential of contamination spread because of fewer components at the drill pipe soil interface. However, use of Alternative 2 methods for injection grouting operations would be considered newer technology with a reduced experience base. This may require some development effort.

Alternative 3's use of equipment similar to Phase 1 equipment and methods is considered technically feasible and may be cost effective for Fiscal Year 2005.

Recommendations: This conceptual design effort recommends that the approach for single fluid injection grouting of contaminant waste zones for the formation of monolithic grouted masses, as well as foundation grouting using a roto-percussion, rotary sonic drill, or rotary drill with fluted bit and injection grouting rig attached to a sufficiently large hydraulic excavator, is a valid approach and commercially practicable.

Alternative 1, using the drill rig attached to a linear mast, is the recommended approach and should provide sufficient similarities to commercial practices for competitive bidding.

This conceptual design recommends the allowance for use of used equipment based on vendor desires. This allowance should provide some means for potential bidders to reduce their project risk.

This EDF also recommends further study of Alternative 2 of using a mastless drill head and active hydraulic sensing and controls, provided funding is available. This alternative may minimize the complexity of operations and minimize the number of personnel required to meet the production schedule.

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6. Review (R) and Approval (A) and Acceptance (Ac) Signatures:
(See instructions for definitions of terms and significance of signatures.)

	[redacted]	Typed Name/Organization	Signature	Date
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Requestor (if applicable)	Ac	David F. Nickelson, PE, 3F20		9/29/04
Doc. Control				

7. Distribution: (Name and Mail Stop)

8. Does document contain sensitive unclassified information? ☐ Yes ☒ No
If Yes, what category:

9. Can document be externally distributed? ☒ Yes ☐ No

10. Uniform File Code: 6104 Disposition Authority: ENV1-j-1
Record Retention Period: Cutoff at the end of the program or project. Destroy 75 years after cutoff.

11. For QA Records Classification Only: ☐ Lifetime ☒ Nonpermanent ☐ Permanent
Item and activity to which the QA Record apply:

12. NRC related? ☐ Yes ☒ No

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ACRONYMS

API	American Petroleum Institute
EDF	engineering design file
FY	fiscal year
GIS	geographical information system
INEEL	Idaho National Engineering and Environmental Laboratory
ISG	in situ grouting
ISO	International Standards Organization
MCP	management control procedure
OSHA	Occupational Safety and Health Act
RWMC	Radioactive Waste Management Complex
SDA	subsurface disposal area
TFR	technical and functional requirement

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OU 7-13/14 In Situ Grouting Project Hydraulic Excavator and Drill-Injection Rig

1. PURPOSE

This engineering and design file (EDF) provides conceptual design information for the hydraulic excavator and drilling/grout injection rig for in situ grouting (ISG) of select areas of the Subsurface Disposal Area (SDA) at the Idaho National Engineering and Environmental Laboratory's (INEEL's) Radioactive Waste Management Complex (RWMC) for the Operable Unit 7-13/14 Phase 2 ISG Project.

2. BACKGROUND

The INEEL is a U.S. Department of Energy National Laboratory located approximately 50 miles from Idaho Falls, Idaho. Several discrete disposal locations in soil vault rows, pits, and trenches in the SDA will be remediated by single fluid nondisplacement ISG over a span of several years. Chemically and radiologically contaminated soil and debris may be encountered during remedial action activities. The SDA consists of an approximate 97-acre fenced area containing 20 pits, 58 trenches, and 21 soil vault rows. The depth of the area from surface to bedrock varies from approximately 15 to 30 ft. Vertical sections of the area contain waste zones consisting of underburden soil, waste burial zones, and overburden soil, as well as native soil in between the disposal areas.

The current envisioned project is to inject cementitious grout into the subsurface to approximate maximum depths of 25 ft, forming monolithic columnar blocks or spaced vertical support columns. Pits and trenches were typically constructed originally by excavating undisturbed earth to bedrock (15- to 25-ft depth) and backfilling the excavation with several feet of clean fill in order to create a disposal volume. This volume would then be filled with various types of wastes. Typical wastes would include drummed wastes (55-gal), large wooden boxed waste, and construction and demolition wastes. Other nontypical wastes may also be contained within some waste volumes. After the disposal volumes were filled, an additional layer of clean fill would be added to close the volume, and some additional soil cover has been added since the initial closure to fill subsidence areas and provide drainage contouring. Soil vaults are unlined and were normally constructed using 6-ft augurs. Waste was placed in the vaults, which were then closed with a soil cover.

Low-level waste pits and trenches within the SDA at RWMC will be grouted to form a monolith totally encapsulating the waste. Transuranic pits and selected trench areas will be grouted with a wider spacing of columns sufficient to support a future cap.

The low-level waste under consideration lies beneath an area of about 11.1 acres and occupies a volume of about 1,320,000 ft^3. The transuranic pits and trenches are spread over an area of 15.4 acres and occupy a volume of about 2,330,000 ft^3.

3. SCOPE

This EDF prepares alternative conceptual designs for a grout injection drill rig and hydraulic excavator for Phase II ISG of selected areas of the SDA, and selects a baseline conceptual alternative for purposes of enabling follow-on preparation by others of the following:

- A conceptual design cost estimate for project documentation
- A hazards analysis for project documentation
- An environmental assessment for project documentation
- A procurement Performance Statement of Work for inclusion in a future performance-based Request for Proposal.

4. REQUIREMENTS

Requirements for the Phase 2 excavator drill unit are identified by two types of bases. These include technical and functional requirements (TFRs) as described in TFR-267, "Requirements for the OU 7-13/14 In Situ Grouting Project (Customer, Project, and System)," and additional design criteria as identified in this EDF.

Technical and functional requirements are developed for a project before the conceptual design process by project staff and approved by the project engineer. TFR-267 was developed as high-level requirements for ISG. During the conceptual design process, the TFR requirements are reviewed and investigated by the conceptual design engineers. The conceptual design approach is then developed from the investigation and analysis of these customer requirements and the conceptual design is then created. The engineer then develops and specifies design criteria unique to the individual subsystems for subsequent detailed design.

Table 1 identifies applicable requirement as defined in TFR-267. Additional design features are listed as salient features under the system design discussion.

Table 1. Technical and functional requirements defined requirements.

TFR	Para	Requirement	Note
267	2.1	The systems shall be capable of providing grout and injecting it into the ground at specified locations.	
267	2.2	The system and components shall be categorized as consumer grade.	High-pressure components, including the swivel may be safety significant, (see EDF-5102, "OU 7-13/14 In Situ Grouting Project Grout Delivery System")

Table 1. (continued).

TFR	Para	Requirement	Note
267	2.3	Grout is typically pumped into the waste zone using high pressure. Injection tools are inserted into the waste zone in a tightly spaced pattern. Grouting is accomplished without displacing contaminants or debris, or ground heaving. Containers of waste are breached and filled from the inside with grout. This method produces interlocking columns of grout, extending from the underburden soil up through the waste, terminating at the subsurface in the overburden. The interlocking columns cure into a solid monolith with no discernable edges between columns.	INEEL/EXT-01-00278, *Evaluation of In Situ Grouting for Operable Unit 7-13/14*
267	3.1.1	Drill string covering shall be provided to reduce personnel contamination from grout splatter.	
267	3.1.1	Air sampling or monitoring system shall be provided around the injection points to monitor hazardous gas releases.	
267	3.2.1	Selected contaminant grouting and foundation grouting grouts shall be compatible with the high-pressure ISG system, as determined by density, suspension, particle size, set time, viscosity, shrinkage, heat generation, and application safety.	
267	3.2.1	Contaminant grout monoliths are desired—adjacent grout columns shall overlap or be contiguous.	
267	3.2.2	System shall provide the capability to locate the drill injection position on the surface to within ±1 ft relative to the map coordinates. It shall be possible to record manually or remotely the location using commercially available equipment.	Interface with instruments and controls
267	3.2.2	System shall provide the capability to measure the vertical position of the injection pipe down hole to within ±1 ft. It shall be possible to record manually or remotely the vertical position using commercially available equipment.	Interface with instruments and controls
267	3.2.2	System shall provide the capability to measure the depth of the drill penetration—the start of grouting position to within ±1 ft. It shall be possible to record manually and remotely the depth of penetration using commercially available equipment.	Interface with instruments and controls

Table 1. (continued).

TFR	Para	Requirement	Note
267	3.2.2	System shall provide the capability to measure the depth of the end of grouting position to within ±1 ft. It shall be possible to record manually and remotely the grouting depth using commercially available equipment.	Interface with instruments and controls
267	3.2.2	System shall provide the capability to measure (qualitatively rough order of magnitude – visually) the volume of grout returns on the surface. It shall be possible to record manually or remotely the volume using commercially available equipment.	Interface with instruments and controls
267	3.3	The system shall employ single-phase high-pressure in situ jet grouting techniques developed and demonstrated at the INEEL for stabilization of SDA pits and trenches.	Single fluid, cementitious-based grout
267	3.3	Contaminant grouting shall be conducted from the basalt layer or drill stem refusal to the interface of the waste and overburden interface.	
267	3.3	The ISG Project shall be conducted as a Comprehensive Environmental Response, Compensation, and Liability Act Section 104 non-time-critical removal action.	
267	3.3	System shall be designed under the applicable radiological work permit—this shall include requirements for portable personnel airborne monitoring equipment, portable personnel exposure monitoring equipment, and portable personnel contamination control equipment.	
267		All mechanical components shall be capable of meeting specified performance at an elevation of 5,000 ft above sea level.	
267		The system shall include features in the design to facilitate deactivation, decontamination, and decommissioning of all components and equipment.	
267		All electrical components shall be capable of meeting specified performance at an elevation of 5,000 ft above sea level.	
267		Cold demonstrations of grout equipment and procedures will be necessary (in a nonradioactive, nonhazardous environment).	

Table 1. (continued).

TFR	Para	Requirement	Note
267		System shall be designed and constructed as consumer grade per Management Control Procedure (MCP)-540, "Documenting the Safety Category of Structures, Systems, and Components."	
267		All procured services and materials shall be consumer grade.	

5. SYSTEM CLASSIFICATIONS, CATEGORIZATIONS, AND DETERMINATIONS

All systems and components are consumer grade. However, high-pressure components, including the swivel, may be classified as safety significant (see EDF-5102 for additional discussion).

6. ASSUMPTIONS

The following are assumptions for the hydraulic excavator and drill-injection rig for the ISG Project:

1. Uncertainty in the area to be in situ grouted in Phase II is defined in Table 2.

2. Uncertainty in the grouting depth of Phase II is defined in Table 3.

3. The maximum depth of ISG is 30 ft from surface level (EDF-4013, "Feasibility Study Technical and Functional Requirements for OU 7-13/14 In Situ Grouting Preliminary Documented Safety Analysis), 33 ft using INEEL spatial analysis map, sda_sediment_thickness_dl_v3.mxd.

Table 2. Phase II in situ grouting low-level waste area.

Scenario	Total In Situ Grouting Project Area (ft^2)	Estimated Total Grout Area Less Than 15 ft Injection Depth (ft^2)	Estimated Total Grout Area 15 to 25 ft Injection Depth (ft^2)	Estimated Total Grout Area 25 to 30 ft Injection Depth (ft^2)
Minimal waste area grouting scenario	262,664	223,716	34,743	4,205
Nominal waste area grouting scenario	525,328	447,433	69,484	8,411
Estimated maximum waste area plus foundation area project grouting	1,166,000 (26.5 acre)	N/A	N/A	N/A

Table 3. Phase II grouting depth.

Injection Depth (ft)	Area (%)
Less than 15	85
15 to 25	13
25 to 30	2

4. Grouting campaign(s) begins in Fiscal Year (FY)-2005 and ends in FY-2010, with decontamination and decommissioning occurring in FY-2011.

5. Conceptual design cost uncertainties are ±20%.[a]

6. Trace alpha, beta, and gamma contamination present within 2 ft of surface.

7. Nominal waste zone starts 3 ft below surface.

8. Mobile equipment means a wheeled or tracked vehicle that is engine or motor powered, together with attached or towed equipment, but not a vehicle operated on fixed rails or tracks.

9. Soils are characterized as typical of the surrounding geology and include basaltic type soils moderately to heavily consolidated. Typical soil breakdown is approximately 37-wt% quartz, 48-wt% clay minerals, 10-wt% calcite, and 5-wt% minor constituents. The climate is high altitude (i.e., 5,000 ft) arid desert.

10. Minimal grouting scenario basis, as presented in Table 2, is from the available geographical information system (GIS) preliminary data, assume 50% of the total area of the low-level waste trenches (i.e., 11 through 58) and 50% of the low-level waste pits (i.e., 7, 8, and 13 through 16) and 50% of the soil vault rows (i.e., 1 through 12 and 14 through 20) are grouted. Assume the areas include an additional 3 ft around the established borders for interface to undisturbed soils (see Appendix B).

11. Nominal waste area grouting basis, as presented in Table 2, is from the available GIS preliminary data, assume 100% of the total area of the low-level waste trenches (i.e., 11 through 58) and 100% of the low-level waste pits (i.e., 7, 8, and 13 through 16) and 100% of the soil vault rows (i.e., 1 through 12 and 14 through 20) are grouted. Data does not include possible areas in Soil Vault Rows 13 and 21. Assume the areas include an additional 3 ft around the established borders for interface to undisturbed soils (see Appendix B).

12. Estimated maximum project grouting area, as presented in Table 2, includes additional interstitial areas and possible foundation grouting area in Pits 17 through 20.

13. Phase II grouting depths, as presented in Table 3, are shown for waste area grouting depths; assume all grouting depths are similar to waste area grouting depths.

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a. L. Marlar, 6-23-04.

7. DESIGN CRITERIA

7.1 Applicable Design Codes and Standards

The following conceptual listing of applicable codes and standards relate to implementation of the Phase 2 ISG Project using commercial grade equipment. This listing clarifies, or is in addition to, equipment design codes and standards normally used by a vendor for design and fabrication of equipment.

- Factory Mutual Datasheet 7-40, "Heavy Duty Mobile Equipment"
- International Standards Organization (ISO) TC 127, "Earth Moving Equipment"
- Occupational Safety and Health Act (OSHA) Regulations
- Safety and hazard warnings: ISO Standard 9244:1995, "Earth-moving machinery—safety signs and hazard pictorials—General principles."

Equipment procurement specifications will be based on general operational and performance capabilities of commercial grade equipment, which implies conformance to industrial regulation. A detailed listing and discussion of design and fabrication codes and standards is beyond the scope of this EDF. However, standards applicable to hydraulic excavators are covered under ISO standards, under ISO TC 127, which also covers other earth moving equipment. A draft subset listing of applicable standards of ISO TC 127 for hydraulic excavators provided by D. Gamble-John Deere Co. is provided in Appendix A.

Standards for jet grouting equipment and processes are less evolved than for earth moving equipment. As of 1997, American standards for jet grouting both lagged and referenced the European Committee for Standardization finalization of standards for the jet grouting industry. Appendix A provides discussion on standards for the jet grouting industry. The American Petroleum Institute (API) includes many suggested practices and specifications for high-pressure components primarily used in the petroleum industry. Some of the API documents, but not all, are cross referenced to ISO standards. Future procurements should specify, or request as part of a subcontract, sufficient detail to address safety of design and operation in addition to available standards for the injection grouting equipment.

7.2 System Design Discussion

Three alternatives are presented for the trackhoe and drill rig system conceptual design. These alternatives include a hydraulic excavator with mast mounted drill-injection rig, a hydraulic excavator with nonmast drill-injection rig, and an alternative for reuse of the existing Phase 1 drill-injection rig with or without modifications for cementitious grout. The first alternative is discussed in the most detail. The latter alternatives are discussed as variances from Alternative 1 or as stand-alone programmatic paths.

Alternative 1—This alternative includes a hydraulic excavator with a mast mounted drill-injection rig as illustrated in Figure 1. Salient features are itemized as follows:

- Equipment that includes an integrated hydraulic excavator with a roto-percussion, rotary sonic drill, or rotary drill with fluted bit end effector and a high-pressure pump system integration with the injection system, including hose management systems, monitoring and control systems, and all accompanying documentation.

- Equipment that must operate on SDA waste area surfaces should have ground pressures of 2,000 psf or lower. Mats, platforms, or other means to reduce ground pressure should be provided for equipment with ground pressures exceeding this value. During wet conditions or where overburden depths are less than 3 ft, ground pressures should be 1,500 psf or lower.

- The system and operations shall meet OSHA standards.

- Fire protection shall be in accordance with Factory Mutual Datasheet 7-40.

- Equipment shall be able to perform contamination stabilization grouting or foundation grouting.

- Foundation support grout injection to provide spaced structural support columns for potential cap.

- System shall be able to monitor actual variation in elevation of the drill string bit, and the location of the nozzle injection planes during the injection process. The system should control normal variations in elevation of the injection planes to ±1/4 in. during injection activities.

- Production of up to 3 to 8 holes per hour to nominal depth of 15 ft, capability to inject to 25 ft.

- Contamination grout injection to provide monolithic waste zone solidification through repetitive soil-crete column production.

- Single fluid cementitious jet grouting, with one or more injection nozzles.

- Contamination grout injection into known characterization of overcover fill, unknown characterization of waste matrix, and known characterization of undercover fill areas having been known as previously excavated and filled and patched in prior decades.

- Hole spacing for monolithic waste zone solidification 20 in. each leg on triangular pitch.

- Accuracy of surface hole placement ±1 ft (basis: program direction).

- Hole spacing for structural support columns 10 to 12 feet on center. Grout injection operation(s) to minimize radiological or hazardous exposure to operational personnel, and the environment.

- Water system to actuate pipe wiper and supply water spray for pipe and end cleaning (e.g., supply tank, pump, wiper seal, and spray nozzles).

- Contaminant fixative system to spray fixative on grout returns after grouting (e.g., supply tank, pump, and spray nozzle).

- General and local area monitoring for radiological controls, industrial hygiene, and data acquisition.

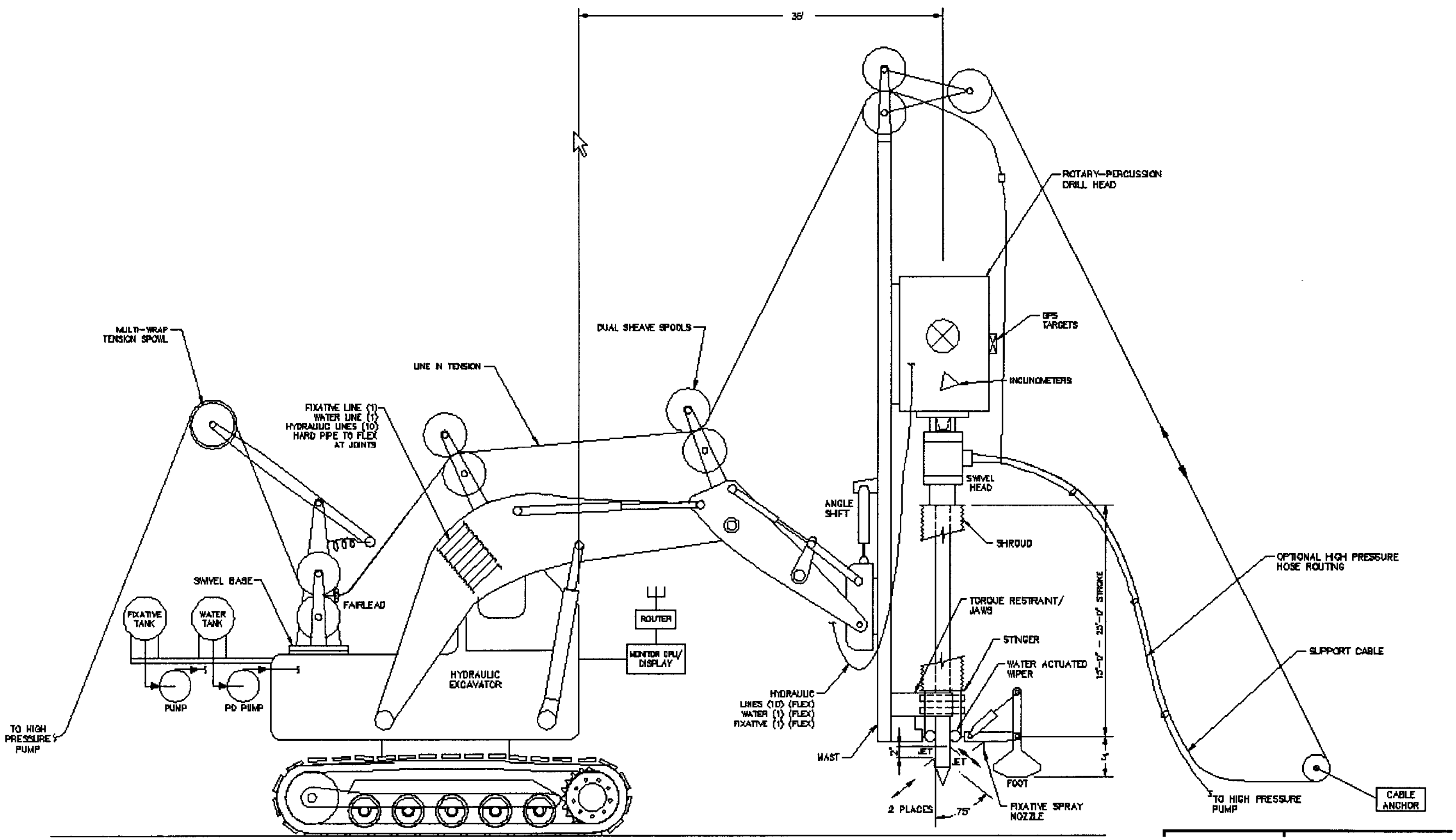

Figure 1. Alternative 1 excavator and drill rig configuration.

Excavator salient features:

- 35 to 40 ft reach from cab to drill string
- Structural rigidity of machinery linkages and pins to maintain accuracy of hole and column placement
- Sufficient hydraulic capacity to power excavator and the drill rig
- Ground pressure less than 2000 lb/ft^2 for dry conditions, 1500 lb/ft^2 for wet conditions or for shallow overburden
- Kicker support foot, load locks, or means to minimize hydraulic drift
- Nominal excavator size class 90,000 lb or greater
- Vertical reach sufficient to extract drill stem with bit and mast 3 ft above ground
- End motion to enable laying drilling rig horizontal
- Safety systems—cab safety interlocks, flashing lights, audible alert warnings, placarding, and communications system(s)
- Automatic lube system
- 110-volt AC power sufficient to power monitors, sensors, cameras, and other extra oversight or data acquisition equipment (approximately 1 to 5 kW)
- Commercial grade cab pressurized through an air-conditioned filtered air system to maintain operator comfort; workspace to be periodically assessed and controlled to industrial hygiene and radiological control guidance
- Data acquisition system and secure wireless uplink hardware
- Hose management sheaves and reeving on top of boom and stinger, or alternatively, a hose attached to the swivel and to ground with safety cable and anchored take up hoist reeving, or alternatively, using an expandable cable tray with a u-bend to track the mast vertical motion
- Visible flashing light (yellow) to indicate operational status
- Fixative spray system interface at the bottom of the drill rig to spray bright colored fixative on top of the grout returns to fix any potential contamination
- Emergency shutdown switch(s)
- Nonflammable or minimal flammable hydraulic fluid
- Dry chemical fire suppression system in engine compartment
- Local fire extinguishers.

Mast mounted drill-injection rig salient features:

- Rotary percussion drill head, rotary sonic drill, or rotary drill with fluted bit
- Rpm nominal 25 to 30, 0 to 50 rpm rotational range
- Percussion or resonant sonic specific impact energy nominally sufficient to drive a 4-in. diameter, 60-degree cone bit through compacted native clayey soil, the soil having a standard penitrometer reading of 100 blows per foot, to a depth of 25 ft in 2 minutes[b]
- Vertical drill travel through linear mast motion
- Drill pipe torque restraint (breakout tools) assembly at the bottom of mast assembly
- 15 ft nominal injection depth, max depth 33 ft, range 15 to 33 ft
- Injection interface swivel
  - For up to 10,000 psi injection pressure
  - Interface with grout injection line
  - Abrasive cementitious grout
  - Torque restraint
- Single fluid cementitious grout
- Operation with 2 or 3 injection nozzles for normal operation, single injection under partial mode, (basis: two or more nozzles being redundant and operationally conservative reduces chances of pressure spiking; single is allowable and may provide greater energy deposition, but is less operationally forgiving)
- Injection nozzle flow range 0.1 gpm trickle flow to 50-gpm nominal total flow through 2 or 3 nozzles at 8,000 psi (see EDF 5135, "OU 7-13/14 In Situ Grouting Project Grout Storage and Mixing," for additional discussion on high-pressure pump sizing and EDF 5102 for column production)
- Injection capability during downward or upward motion
- Injection angle nominal 10 to 15 degrees downward from horizontal
- Vertical motion control at 1/4-in. increments or controlled slow ascent (descent) to ensure injection plane overlap and mixing in the formed column
- Elevational stability of the grouting jet planes ±1/4 in. during grouting at increment or during slow vertical motion (desire stable grouting planes to promote grout soil interaction)
- Vertical motion rate fixed at 2.5 vertical ft/minute or variable rate range 1 to 4 ft/minute (see EDF-5135 for hole production discussion)

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[b] Basis E. Carter e-mail 4-26-04

- Optional load pad/kicker foot to preclude grout/mud buildup, and reduce hydraulic drift
- Drill string shroud and pipe string interface stinger with internal pipe wiper(s) or approved alternative arrangement using a filled double wiper assembly and no shroud
- Drill stem diameter nominal 3.5 in., range 2.0 to 4.0 in.
- Drill stem interface—quick change remotized
- Normal maintenance to be performed in horizontal position
- Normal routine maintenance (see EDF-5155, for additional discussion)
    - Swivel—biweekly
    - Injection nozzles and drill bit—daily through bit box
    - Grout injection hose—biweekly.
- Operator control in cab, remote data acquisition to data link to control facility
- High-pressure grout injection hose: 20,000 psi rating hydraulic hose, 2 in. OD × 1/2 in. ID at fittings (basis Phase 1 hose), or preferred alternative using a 5 in. OD, 2 in. ID, 10,000 psi rated cementing hose, See EDF-5102 for more discussion on the high-pressure hose.

7.2.1 Alternative 1 Discussion

Alternative 1 includes a large hydraulic commercial excavator combined with a mast mounted roto-percussion or rotary sonic drill rig configured for impact or rotary drilling and high-pressure grout injection. The configuration is presented in Figure 1, as well as in Sketch 1 of Appendix C. The conceptual design uses a commercially available hydraulic excavator to maximize reliability of operation. The excavator would be modified only minimally to incorporate safety or operationally required components; these include any additional safety interlocks, monitors, cameras, cleaning systems, and contaminant fixative special spray systems.

Primary factors in the configuration of the excavator and drill rig are the methods and components included to minimize the potential for spread of contamination emitted from the grout hole. Minimization of contamination includes locating the drill pipe safely away from the operator cab, precluding any operations or oversight personnel near the grout hole while in operating mode, configuring a system assembly and operational procedure that minimizes soil and grout return accumulations, providing component active cleanup and wash systems, and controlling or fixing the grout returns as they evolve at the surface during grouting operations.

Alternative 1 configuration includes a kicker foot located at the bottom of the drill mast. This foot serves two functions. First, it provides a means to stabilize the mast during operations through interface with the ground. This stabilization reduces the need for advanced hydraulic controls to maintain rigidity, and may enable the use of lower cost or used financially depreciated excavators. The second function of the foot is to provide a kicking action to dislocate soil or potentially contaminated grout accumulated on the foot during operations.

A torque restraint system (i.e., breakout tools) is located at the bottom of the mast. The restraint system includes dual sets of pipe jaws to enable breaking the pipe joints without the use of the drill head.

The pipe jaws also serve as sets of pipe rams to hold a stinger interface during normal operations. The stinger interfaces with the pipe shroud as depicted in Figure 1, and houses one or more pipe wipers.

In addition, a contaminant fixative system is configured to the excavator and drill rig bottom to spray a layer of fixative on the grout returns at the end of grouting operations. The fixative would be brightly colored to aid in visualization of the fixed area. Other monitors, as directed by radiological control or industrial hygiene, may be located at the bottom of the mast assembly for oversight monitoring of the local injection site

Location of the drill pipe approximately 30 to 35 ft from the operating cab is considered a safe distance for conceptual design purposes and conforms to the As Low As Reasonable Achievable principles of time, distance, or shielding. This distance requires an excavator of sufficient size and rigidity to provide the reach and maintain accuracy of hole and column placement during operations. Based on review of commercial drill rig products in the general size range to accomplish 20 to 30 ft drilling and injection, the associated hydraulic excavators needed to handle that size of unit are of the approximate 90,000-lb class or greater.

Figures 2 and 3 illustrate the working range of a 95,000+-class excavator with a standard bucket and with a hypothetical drill attached. A Caterpillar Model 345B excavator is used for illustration. Appendix D provides reference information on a Caterpillar Model 345B, and for a larger 180,000-lb Class excavator, a Caterpillar Model 385. The large unit provides a reach of approximately 50 to 55 ft at the bucket and approximately 30 ft at the end of the main boom. Other makes and models provide similar characteristics.

Figures 4 and 5 illustrate typical actual condition reach capabilities of excavators with attached drill rigs. Figure 4 illustrates a smaller unit with an approximate 21-ft reach, and Figure 5 illustrates a slightly larger unit with a 21.5-ft single pass rock drilling depth capability.

The drill rig would essentially replace the digging bucket on the excavator stick link as an end effector. Alternative 1 for the drill rig includes a mast mount roto-percussion or rotary sonic drill rig configured for impact and rotary drilling and grout injection. The normal operating scenario would be for the operator to locate the tip of the drill string at a preselected hole location using the excavator tracks for periodic movement; using the pivot for angular setup; using the boom, stick, and bucket hydraulic motion controls for hole location setup. The drill string would be placed in the vertical position as measured in two planes. The first vertical alignment would be perpendicular to the boom and stick plane using the excavator controls, and the second would be at 90-degree verticality using the mast side angular adjustment control. An accuracy of placement of the drill tip at the preselected location of ±1 ft and vertical angularity accuracy of the inserted drill pipe of ±1 degree of plumb has been established as adequate for conceptual design purposes. In the latter, a 1-degree verticality misalignment would equate to approximately 0.52 ft over a 30 ft depth ($30 \text{ ft} \times \tan 1^\circ = 0.52 \text{ ft}$). The 1-degree verticality misalignment is considered a commercially practical value based on hydraulic excavator pile driving practices using modern hydraulic controls as illustrated in Figure 6, provided the drill pipe has sufficient rigidity to minimize deflection during drilling and grouting and the drilling procedure minimizes deflection. Alternative 2 discusses these controls in more detail and vendor information is referenced in Appendix H.

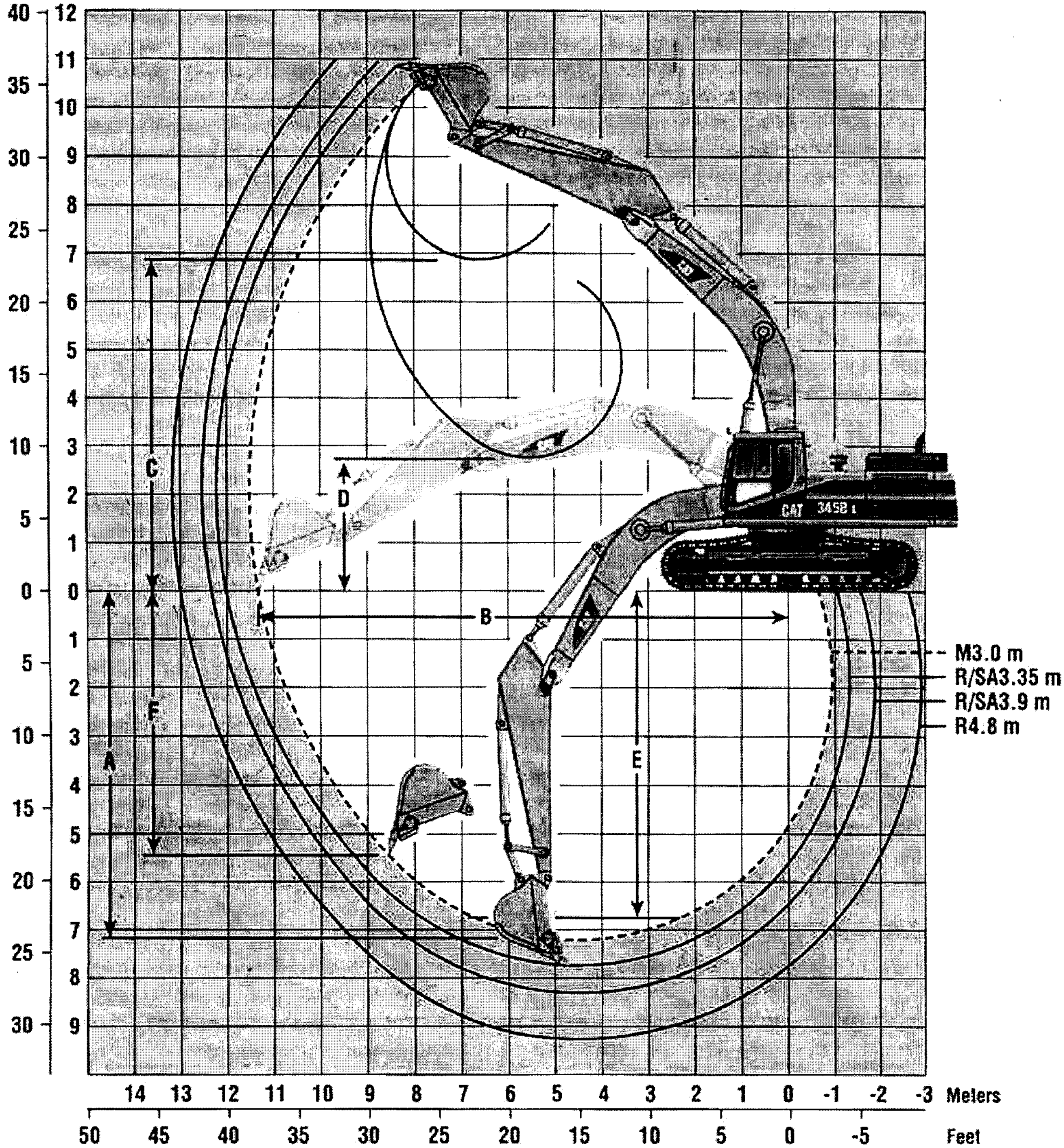


Figure 2. Working range of 95,000-lb class excavator (Caterpillar 345B).

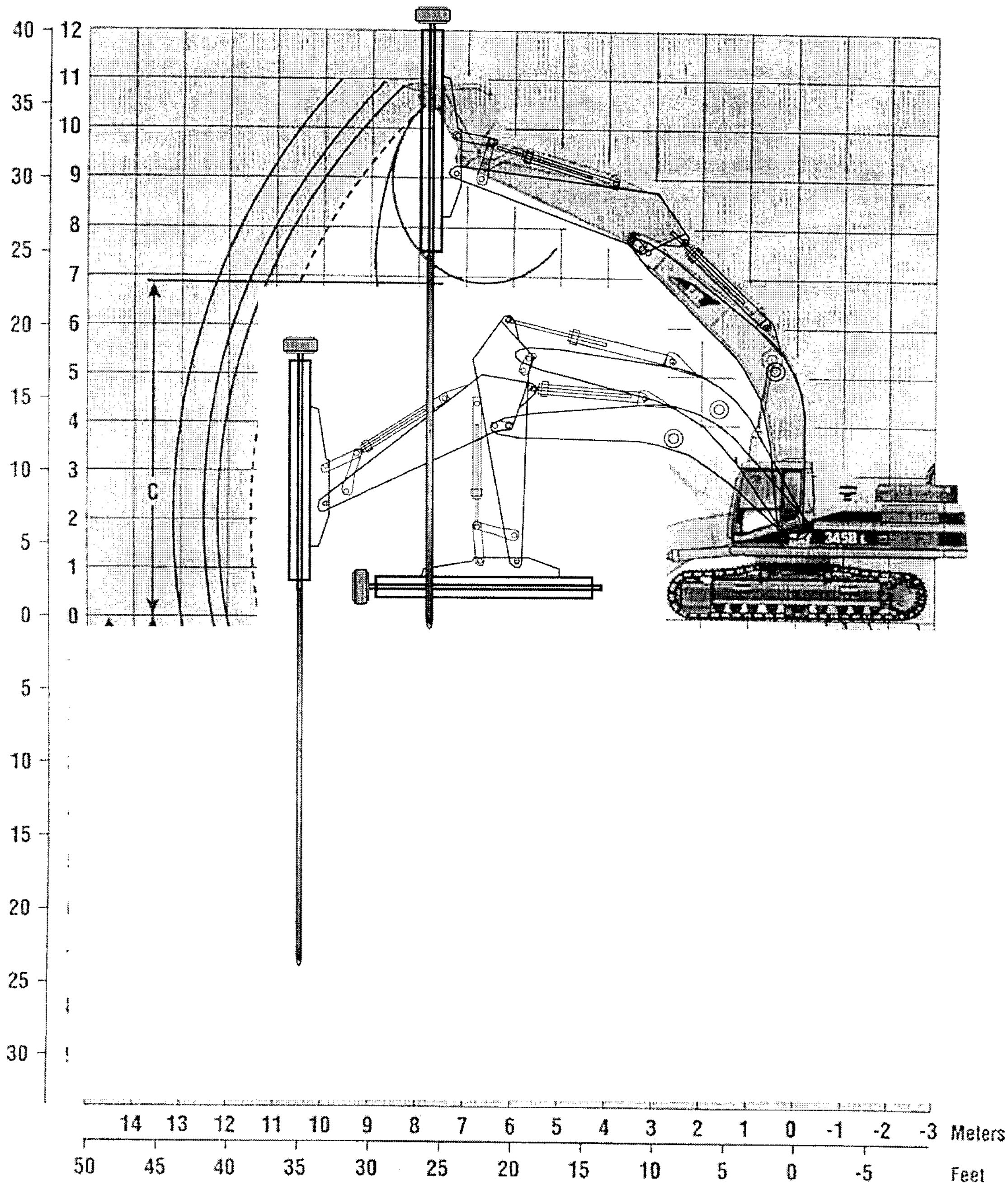


Figure 3. Hypothical working range of 95,000-lb class excavator with a drill rig attached (Caterpillar 345B).

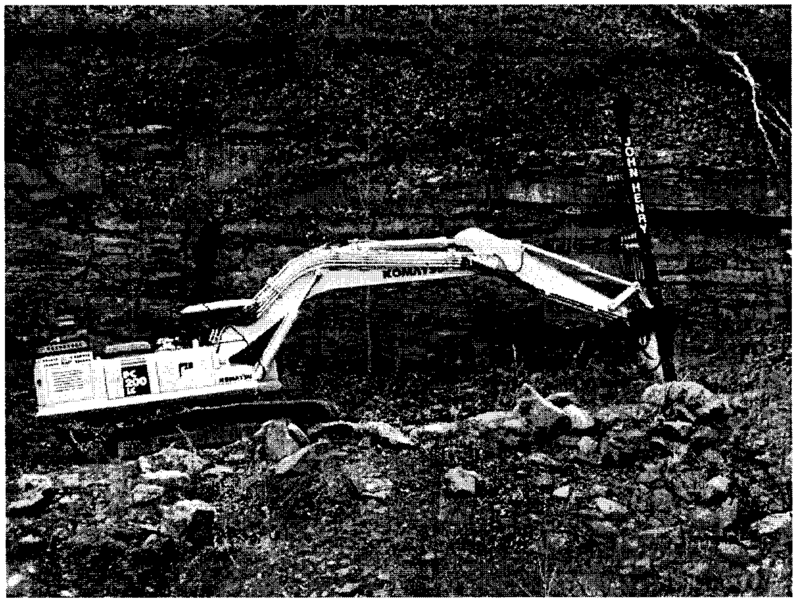


Figure 4. Excavator with attached drill rig (John Henry Co).

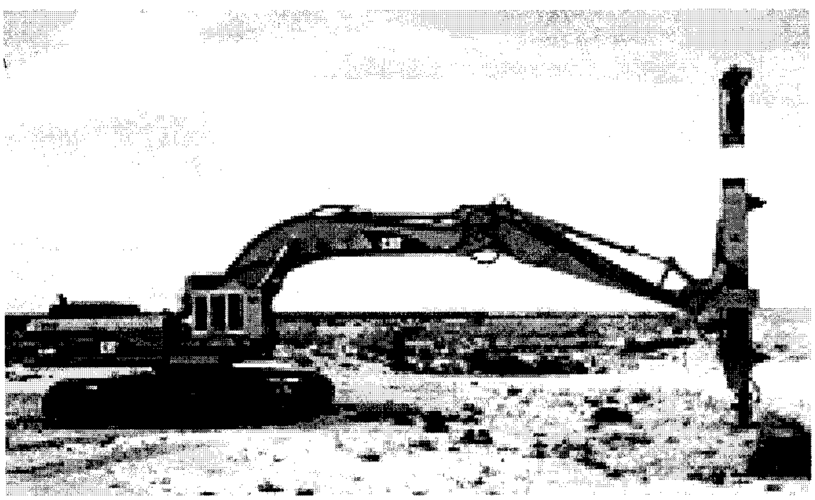


Figure 5. Excavator with attached drill rig (TRAMAC CPA).

Excavators can readily be configured for quick disconnect of end effectors on the stick section; however, these quick equipment disconnects usually are matched with hydraulic hose quick disconnects that require operator presence to disconnect. The desire to maintain operational distance during active operations may steer configurations away from using quick equipment disconnects. As an alternative, normal rig maintenance or changeout may be performed by personnel while the excavator and drill rig are in shutdown inactive mode. In addition, review of industrial safety alerts has identified the misuse or failure of bucket quick disconnects as a recurring source of accidents in the past.

Alternatively, the excavator stick section could be removed and the drill rig could be mounted directly to the excavator boom section to provide a potentially more rigid structure at the expense of loss of some reach and motion control. This type of configuration is illustrated in Figure 7 with an auger drill rig on a 90,000-lb class excavator. Additional information is provided in Appendix E. With this configuration, a longer boom, potentially nonstandard but commercially practical, may be required in order to provide sufficient reach of 30 to 35 ft.

Figure 6. Hydraulic excavator pile driving configuration (Hercules Machinery Corp.).

Control of drill rig angular verticality (plumbness) to maintain acceptable column injection location and formation may be accomplished through several methods:

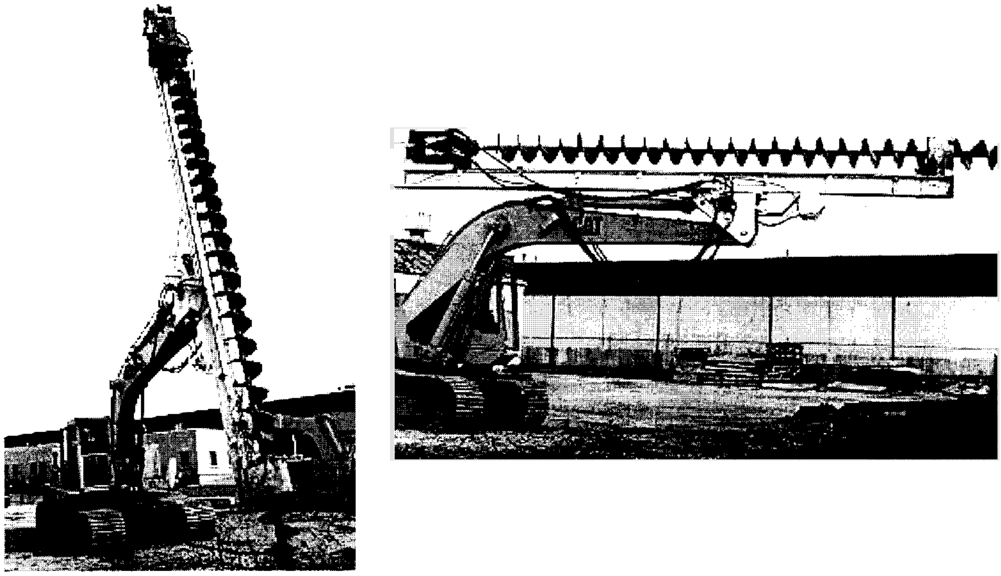
- The method included in the Alternative 1 configuration includes the use of the kicker foot as discussed above. The kicker provides a means to stabilize the mast during operations through interface with the ground. This stabilization reduces the need for advanced hydraulic controls or components to maintain rigidity, and may enable the use of lower cost excavators.

- An optional method is the purchase of newer equipment with pilot-operated control circuits. These systems use pilot pressure systems (e.g., 500 psi pilot with 1,500 to 3,000 psi active) and use components generally manufactured to closer tolerances; therefore, inherently tending to minimize drift when compared to standard hydraulic components.

- Another option is to use hydraulic load checks installed in selected hydraulic circuits to effectively lock the circuit flow and minimize drifting.

- Another option is to maintain active hydraulic flow control with computerized monitoring and feedback on select hydraulic circuits. These types of controls include sensors, feedback loops and signal cables, and industrialized computer hardware that are commercially available.

- Drill pipe of sufficient rigidity is used to minimize deflection while in the drilling or grouting modes.



- 30' (9.1m) maximum drilling depth
- 30" (762mm) maximum drilling diameter
- 30,000 lb (133 kN) extraction force
- 15,000 lb (66 kN) crowd force
- Self erecting
- Designed for excavators of 90,000 lbs and up
- Uses ICE Model 3060 auger or equal
- Adjusts fore & aft using excavator cylinder.
- 10° side-to-side adjustment
- Controlled by excavator joy-sticks
- No modifications to excavator hydraulic system
- Optional 3" (75mm) grout swivel

Figure 7. Drill rig mounted on the excavator boom (ICE Model 3030).

The vertical linear positioning of the drill head and the drill string is accomplished through actuation of the of the mast linear control system. This linear control may be through hydraulic rams or a hydraulic motor with chain and sprocket assemblies. Once the mast is set in place, the vertical downward drilling and upward grouting are controlled through the mast vertical controls.

Grout Injection—types of commercial injection grouting include single and multiple fluid grouting. Multiple fluid grouting employs subsurface erosion and grout backfilling techniques using two or more fluid streams, whereas single fluid uses only one pressurized fluid. Multiple fluid grouting generally emits large quantities of surface spoils displaced from the erosion actions and is undesirable for this project. High-pressure single fluid grouting promotes direct interaction of the grout with the material in the zone of influence (creation of "soil-crete"). The zone of influence is generally referred to by using the column diameter nomenclature, but is based on many technical factors, including system and nozzle exit pressure, jet orifice size, fluid composition, mass and viscosity, soil composition, void space, particle size, and soil consolidation. Single fluid grouting is the preferred approach in order to minimize the soil displacement effects of erosion jetting before grouting. Appendix F provides background on single fluid and multiple fluid jet grouting.

The conceptual configuration of the drill string is for one drill pipe of sufficient length to enable single pass drilling and single fluid grout injection (no added drill pipe sections), using one or more injection nozzles. High-pressure grout fluid is routed to the drill pipe through a swivel located on the bottom of the drill head. The swivel provides an interface from the static high-pressure hose connection to the rotating drill string through the rotary head. Appendix G provides information on a typical high-pressure swivel. Appendix G illustrates a 6,000- to 8,000-psi swivel. A 10,000-psi rated swivel would be a special order based on the typical 8K design. The swivel is usually placed on the bottom of the drill head; however, alternate drill head designs may place it at the top. In this case, the drill head would use a hollow internal shaft to complete the fluid circuit.

Drill pipe and bit rotary and percussion motions are supplied by the drill head. These motions are hydraulically powered for this alternative, but may be powered by air or electricity. The drill head may be either a rotary percussion rock drill type of drill head or a rotary resonant sonic type drill head.

The rotary percussion rock drill type drill head is a rotary head that supplies a percussion impact force to the drill string. These drill heads typically operate in the 10- to 60-hz range for percussion impact events. The impact forces of the percussion heads provide a shock force through the swivel and drill string to the bit, which in turn is transferred to the matrix material for enhanced material removal. Figure 8 illustrates a typical rotary percussion type drill head.

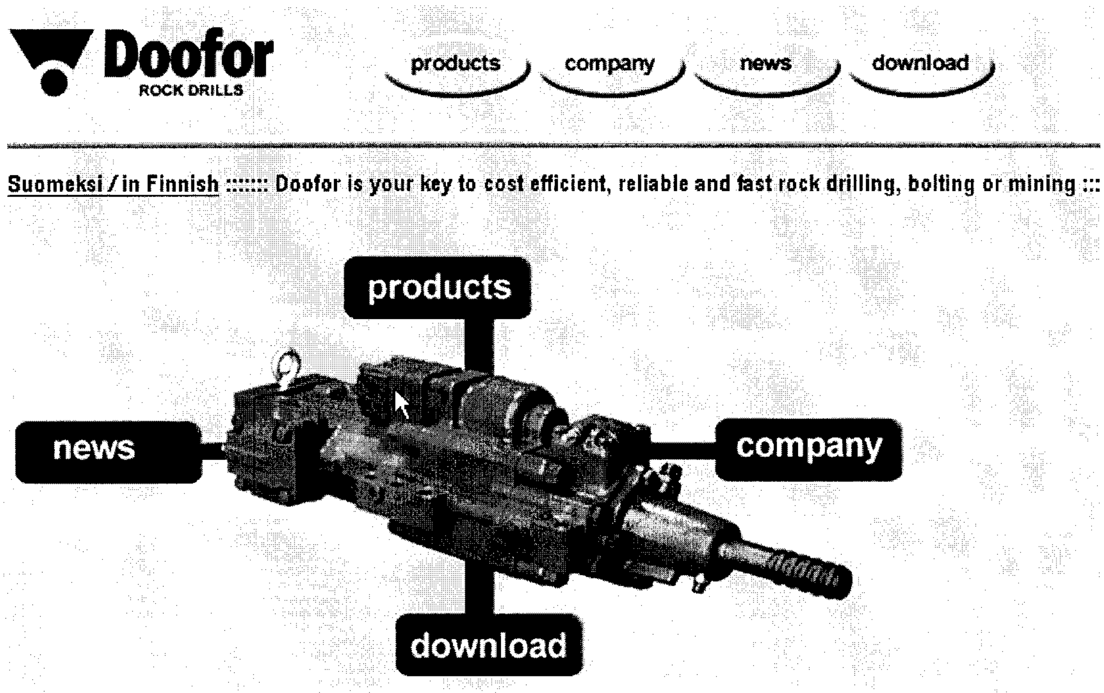


Figure 8. Rotary percussion drill head (Doofer).

The rotary sonic drill head is a rotary head that supplies excitation vibration forces to the drill string and the drill bit. These heads typically operate with three modes of excitation. The first mode, the startup mode, is characterized by low frequency (i.e., less than 2 cps) oscillation with large vertical amplitude (±0.5 to 1.0 in. oscillations). This mode starts the entire drill string mass string in vertical motion. The second mode is characterized by a higher frequency (i.e., 100 to 150 cps), low amplitude (±1/32 in.) vibrational mode that is intended to excite the drill string into resonance. The third mode is resonance mode. In the resonance mode, the higher frequency low amplitude vertical excitation vibrations induce resonance in the string, which induces strong lateral deflections of the drill string. The vertical vibrations and the lateral deflections tend to fluidize the adjacent matrix soil greatly, decreasing drill string sliding friction because of the fluidized matrix material. However, in practice for short drill strings, the drill pipe material is often too stiff and too short to enable a resonant condition to form, with the result being the drill string just operates in a low amplitude high vertical vibration mode. These types of heads are typically larger and heavier than the rotary percussion drill heads with the drill string being coupled to the head through a shock absorbing mechanism, such as air springs and bumpers. This type of drill head has been used successfully for probe insertion into the SDA. Three concerns are recognized for the use of a sonic drill head for injection grouting. The first concern is the potential damping effect the flowing grout may have on the drill string. The second concern is the potential for plating and lump formation (with nozzle plugging) inside the drill string because of interaction of continuous vibrations and the cementitious grout material. The third concern is the heat generated in the drill string by the higher frequency operation may affect the grout setup time. Figure 9 illustrates a patented sonic drill head (Barrow 1996).

U.S. Patent **Oct. 8, 1996** **Sheet 1 of 5** **5,562,169**

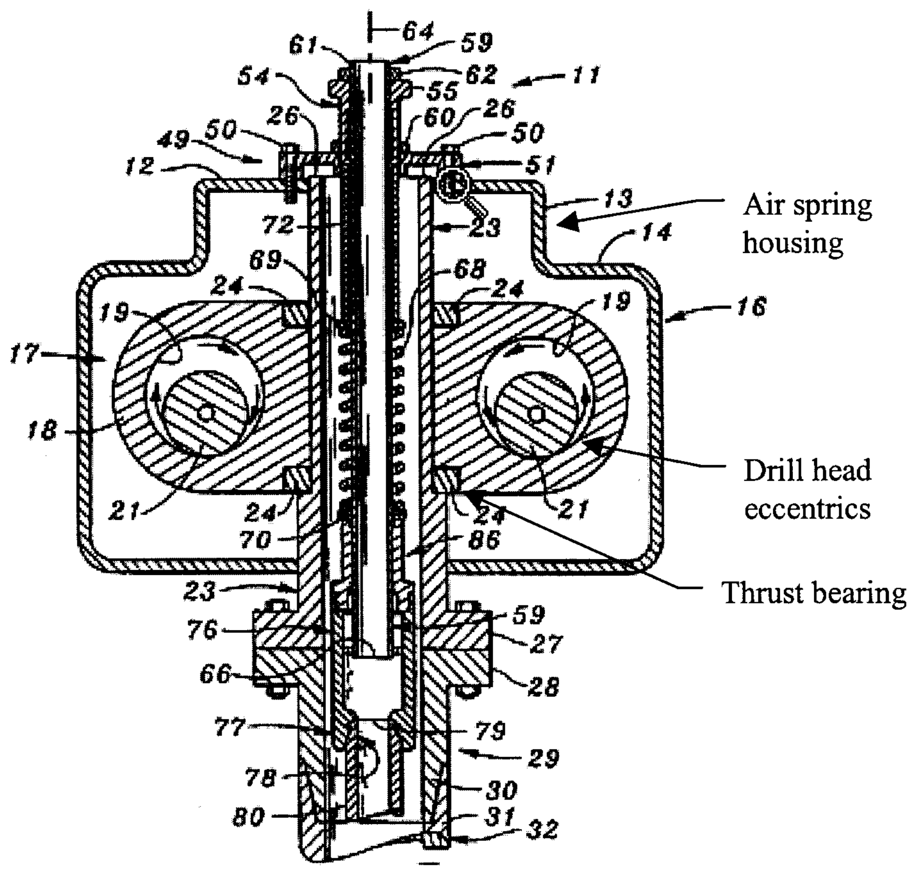


Figure 9. Sonic drill head (US Patent 5,562,169).

The swivel is connected to the drill head through an API-tapered thread for easy remote removal and the pipe is connected to the swivel through a similar thread. The drill string torque restraint (jaws) required for breaking the joint, untorqueing, and removal of the drill string from the head is located at the bottom of the mast assembly. The torque restraint system may also be located away from the drill rig to reduce the amount of equipment and systems near the drill hole interface. Additional reverse rotary motion for unthreading the pipe may be supplied by the rotary head.

The restraint system includes dual sets of pipe jaws to enable initial breaking of the pipe joints without the use of the drill head (the drill head may be use to complete unthreading of the joint). The pipe jaws also serve as sets of pipe rams to hold a stinger interface during normal operations. The stinger is essentially a pipe enclosure with a top flange that interfaces with the pipe shroud as depicted in Figure 1, and houses one or more pipe wipers. This setup is similar to the Phase 1 approach.

The recommended type of drill string wiper consists of a double wiper assembly (reference http://www.deanbennett.com/drill-stem-wipers.htm) that contains Mystic JT-6 waterproof bearing grease or a very soft wax pressurized between the two wipers. This wiper assembly is held in place at the lower location using the mast pipe ram clamps. The wiper assembly enables coating the drill pipe and wiping it as it passes through the assembly in order to prevent formation of potentially contaminated grout dust on the drill pipe above the assembly. This method aids in preventing buildup of grout on the drill pipe and saves cleaning the drill pipe before cleaning the system. This system potentially eliminates the need for a drill string shroud.

The main drill pipe is allowed to remain potentially contaminated. The upper 6 ft of drill pipe remains clean because it never moves downward far enough to pass by the potentially contaminated top wiper or chuck jaws. Figure 10 illustrates a typical double wiper assembly.

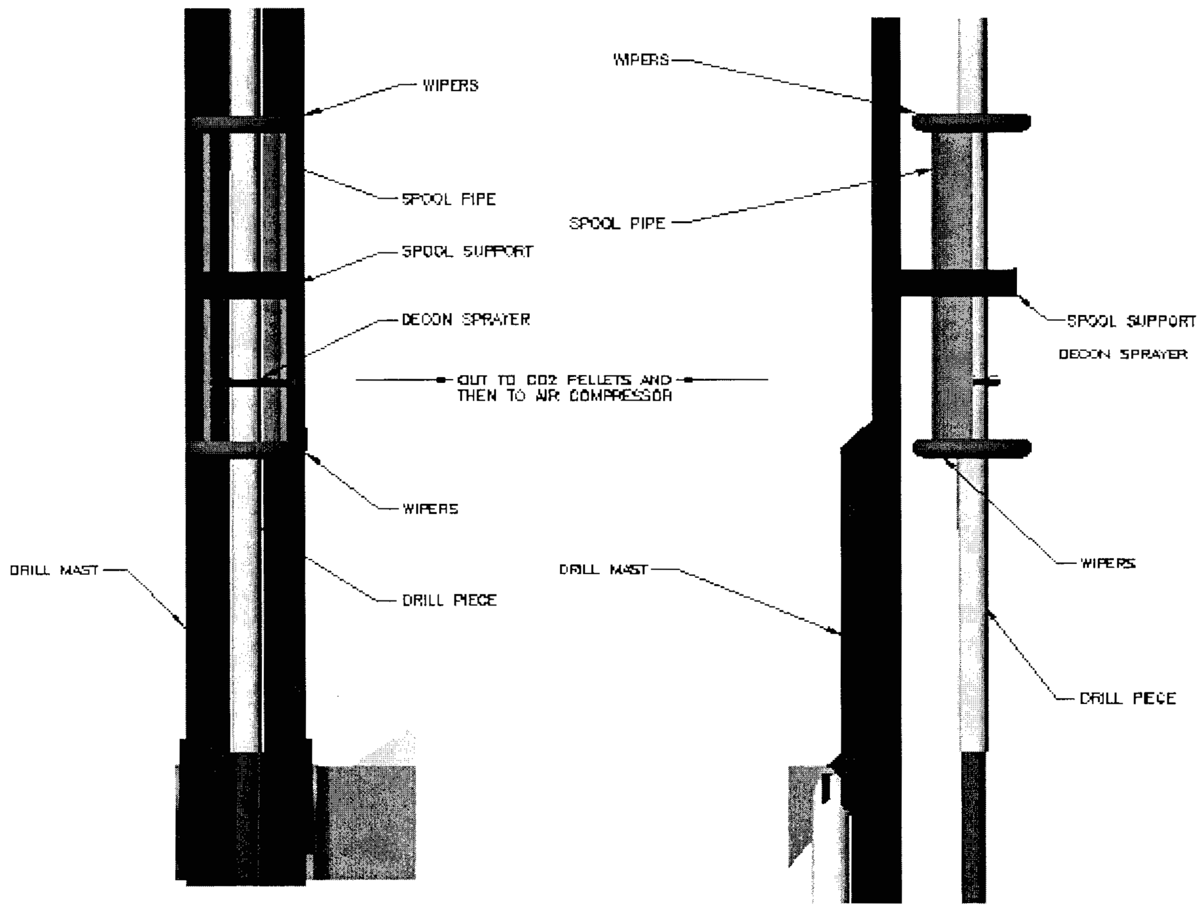


Figure 10. Double wiper assembly.

An alternative wiper assembly uses one or more water-actuated wipers affixed to the stinger at the lower end of the mast and engaged to wipe the drill pipe as it is withdrawn. This type of wiper system may also be used as a localized water spray to aid in cleanup.

In addition, a contaminant fixative system is configured to the excavator and drill rig bottom to spray a layer of fixative on the grout returns at the end of grouting operations. The fixative would be brightly colored to aid in visualization of the fixed area. Other monitors, as directed by radiological control or industrial hygiene, may be located at the bottom of the mast assembly for oversight monitoring of the local injection site.

A combination drilling and injection-grouting bit is located at the bottom of the drill pipe. The conceptual configuration for the bit includes 2 to 3 injection nozzles located above the cutting bit section and 120 to 180 degrees apart to balance the injection forces, and provide redundant grout flow capability. A major operations consideration is the plugging of an injection nozzle. The grout flow from the drill pipe is vertical; this flow changes direction to horizontal at the nozzle location. The internals of the bit provide a sump reservoir for accumulation of grout clumps as the flow transitions to horizontal, which could potentially block a nozzle. This sump provides some backup to minimize nozzle plugging. The use of multiple nozzles provides additional backup should a nozzle plug. The nozzles are pointed approximately 10 to 15 degrees downward from horizontal to enhance column mixing and minimize potential spray at the surface. The nozzles are located at different elevations approximately 2 in. apart to also enhance column mixing. A suite of drill bits of various configurations, and sizing are considered necessary to accommodate unknowns in waste and soil matrix, and operating conditions.

The column formation parameters are conceptually configured as:

- Grout fluid is single phase cementitious.
- Zone consolidation is for monolithic column production using a 24-in. nominal column diameter formed from the depth at bit refusal (assumed at the bottom of the underburden) to the interface of the waste and overburden interface, or a 13-ft average nominal grout distance, with a range to approximately 25 ft maximum depth in select areas.
- Column spacing is 20 in. on center in a triangular grid, allowing for overlap and mixing of columns during grouting.
- Grout injection theoretical volume is 23.6 gal/vertical ft (100% void space) and nominal average injection rate of 13.6 gal/vertical ft (58% void space) intermixed with soil and waste.
- The columns are formed at a nominal vertical rate of 2-1/2 vertical ft/minute, (5 minutes/grouted column 13 ft high) (see EDF 5135 for additional discussion on hole production rate).
- Grout interaction with the soil and waste is configured using 8,000 psi nominal (6,000 to 10,000 psi) injection pressure through two or three nozzles,
- Nozzles are sized to optimize energy deposition into the column to promote interaction, and minimize potential for plugging, nominal 2 to 3 mm nozzle orifice diameter.

Priority operational maintenance for the configuration and equipment include:

- High pressure hose replacement
- Bit replacement
- Swivel replacement
- High pressure grout circuit flushing.

The management and configuration of the high-pressure grout hose from the high-pressure pump is configured for maintaining operational distance during operations and for ease of replacement. As shown in Figure 1 and Appendix C, hose management is configured through reeving through several sets of large diameter reels mounted to the excavator housing, boom, stick, and end effector. A tension take-up spool is located at the rear of the unit to allow a nontension connection to the high-pressure pump. An alternative configuration is also illustrated in Figure 1 and includes attachment of one end of the high-pressure hose to the drill head swivel and the other end to the high-pressure pump. The grout hose is long enough to allow some payout of the hose on the ground. A support cable is attached to the hose and routed through a ground anchored sheave located at some distance from the drill string. A take-up hoist located at the top of the mast is used to take up slack in the pressure hose. Another alternative is to use an expandable cable tray arrangement similar to the Phase 1 cable tray. This type of cable tray allows a u-bed in the tray so one end can track the vertical motion of the mast. Either of the latter alternatives may be the preferred option if the selected high-pressure hose has a sufficiently large minimum bend radius that would dictate excessively large spools for the first configuration. This would be similar to the Phase 1 approach.

The high-pressure hose is identified as a high maintenance component necessitating replacement in lieu of maintenance. The replacement interval is defined per criteria presented in EDF-5155.

The drill bit and nozzles are also identified as high maintenance components necessitating operational changeout and replacement in the drill string. However, once replaced in the string, the bits and nozzles may be serviced and maintained in a controlled area and reused in the drill string at a later time. The replacement interval for bit changeout is estimated at several times per day.

The swivel is also identified as a high maintenance component necessitating operational changeout and replacement in the drill head. As with the bit, once replaced in the head, the swivel may be serviced and maintained in a controlled area and reused in the drill head at a later time. The replacement interval for swivel changeout is estimated at once every 2 weeks.

High-pressure grout circuit flushing is also a high maintenance action. Flushing of the circuit is necessary if the circuit is in an idle mode for a period of time in excess of an established critical threshold time. Idle times in excess of or the established allowable idle time may allow the grout to start to set up, form agglomerations within the grout, or worst case, fully cure and solidify. Once small agglomerations are formed, the circuit may be partially or fully plugged, causing a major shutdown. The critical idle time will be established based on the variables, such as quantity and kind of additives contained in the grout, and weather conditions. This period of time may range from minutes to days, depending on the grout formulation. Longer times would indicate more additives, or more expensive additives, and potentially result in a costlier grout.

Excavator and drill rig fire protection—The hydraulic excavator will be commercially available equipment that is used in general industry. The drill mast is commercially available, but will be customized to support the special requirements for this project. This equipment is specific to the project performance and is not readily replaceable. Therefore, it is being protected in accordance with Factory Mutual Datasheet 7-40.

This datasheet specifies the following requirements. A fixed automatically actuated, multipurpose, dry chemical extinguishing system will protect the engine compartment. Where practical, the hydraulic fluid will be a factory mutual-approved less-flammable fluid. If a factory mutual-approved less-flammable hydraulic fluid is not used, a pre-engineered fixed automatically actuated multipurpose dry chemical extinguishing system shall protect areas where ignition of hydraulic fluid is possible. Means to manually activate the system will be provided in the operator's compartment and at an outside location that is accessible from the ground. The system shall be interlocked to shutdown the engine and hydraulic system when the suppression system activates. At least one 20-lb multipurpose dry chemical fire extinguisher shall be provided on each vehicle. The incorporation of these requirements needs to be evaluated by the fire hazard analysis.

Equipment condition—The program seeks to maximize performance while minimizing costs. The current direction for project implementation is to release a performance-based Request for Proposal and issue one or more performance contracts. The period of performance is conceptualized from issue of contract through FY-2012 on a nonpriority basis with FY-2005 scoping and remainder year scoping. In order to address many of the concerns in a future contract action, a review of some of the issues with the status of equipment used is presented. The issue basically involves the use of new equipment and used equipment. Depending on how the contract is written and what government cost guarantees are included, potential bidders may desire to include used equipment in their plans. The following itemize some issues and assumptions for use of new or used equipment:

- Use of new equipment will require sufficient initial and out year cash flow to support equipment purchase.

- New equipment should have more state-of-the-art components and systems and provide longer project life. New components would include advanced hydraulics and controls as standard equipment.

- The use of used older equipment may provide considerable cost savings to the project or profit potential to the vendor thereby lessening financial risk. However, used older equipment may be operationally marginal for INEEL standards (e.g., used equipment having minor to significant leaks that would be acceptable for commercial project may be unacceptable for INEEL work base on the quantities of leaking fluids).

- Used older equipment would generally be considered as less rigid and less stable than comparable newer equipment of the same class.

- Used newer equipment that has been partially depreciated may provide similar features, such as newer hydraulics as new equipment for some potential cost savings.

Current project projections are for different scope of efforts for the first year of operation (FY-2005) versus out-year efforts. This difference may add complexities to cash flow projection of the potential bidders, especially in the early years. Out-year scoping should be of sufficient magnitude to allow sufficient operation. This conceptual design recommends the allowance for use of used or new equipment based on vendor desires. This allowance should provide some means for potential bidders to reduce their project risk.

7.2.2 Alternative 2 Discussion

Alternative 2 includes a conceptual configuration for injection grouting using a hydraulic excavator and a roto-percussion or rotary sonic drill head as a direct connected end effector. The main difference between Alternative 2 and Alternative 1 is that this alternative does not include a mast for vertical control and positioning of the drill head.

Drill bit positioning to pre-selected surface locations and initial drill pipe verticality (plumb) are accomplished similar to the Alternative 1 configuration. However, vertical linear control of the drill head and attached drill pipe is accomplished through active position sensing, with feedback to active hydraulic control valves for continuous control of the hydraulic circuits. This configuration eliminates the mast, and the kicker foot in the setup, as well as the need or desire for load checks in the hydraulic circuits, in order to minimize drift.

In this alternative, hydraulic fluid is constantly flowing in the control circuits with position sensing and controlled in real-time through computerized control. The advantage of this alternative is the elimination of components, and the potential reduction in the number of operational steps required for setup at each hole location. Reduction in the number of repetitive operational setup steps may transfer to reductions in total time per hole and increased grouted column production per day.

This alternative is considered valid only if active hydraulic control technology is commercially available and reliable under construction type activities with an established experience base.

Figure 11 illustrates vibration impact placement of piles up to 50 ft deep, while maintaining verticality (plumbness) placement control to within 1 degree using boom, stick, and end effector position sensing, feedback and control technology. Appendix H provides additional vendor information for this type of system.

Based on this industry practice as an accepted method of placing piles, the technology is considered commercially available and reliable under construction type activities; however, the experience base using this technique for grout injection is unknown. No systems were found for commercial application of these techniques for the grout injection industry.

Additional review of this alternative may provide improved methods to speed production while minimizing project risk (i.e., contamination) because of the reduction of system complexity and component locations near the hole to surface interface.

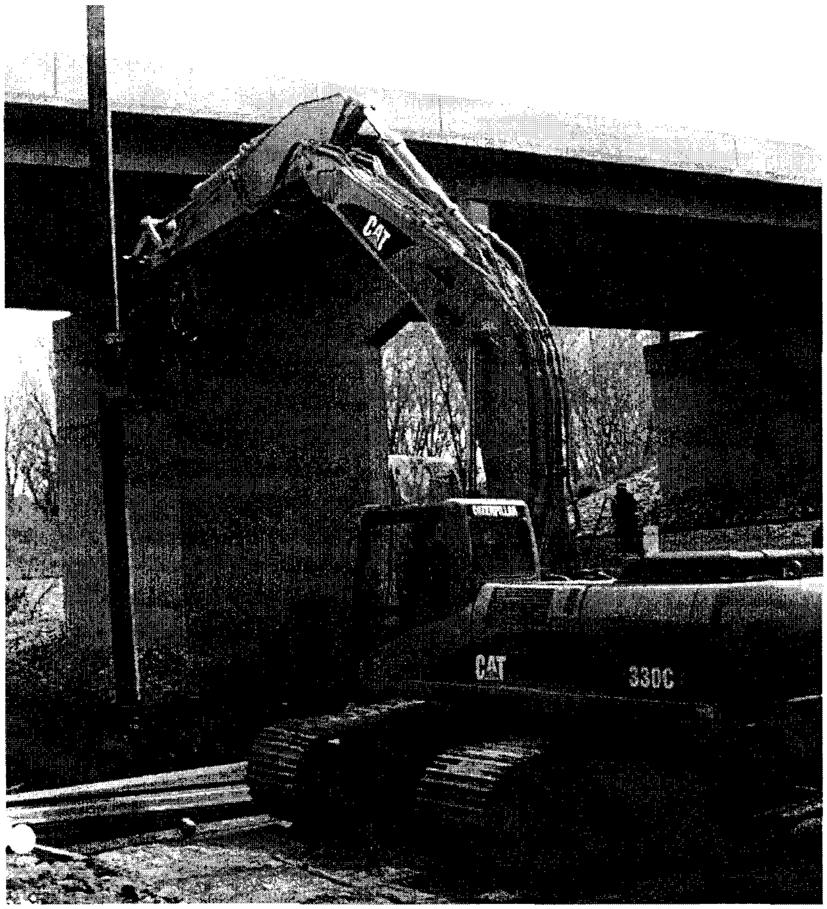


Figure 11. Pile driving using active hydraulic verticality control.

7.2.3 Alternative 3 Discussion

Alternative 3 uses equipment similar to the existing Phase I injection grouting equipment and procedures to the maximum extent possible for Phase II operations. Phase I injection grouting uses a wax-based grout for stabilizing a very localized waste area. Use of similar equipment, procedures, and working plan provides a means for cost savings on Phase II, if feasible and economic to do so.

The Phase 1 project uses a track-mounted close-coupled drill and injection rig. The operator is within the local vicinity of the drilling injection operation, but at a safe distance. The operator controls the unit through a remote control station. However, the drill injection unit has the potential to become contaminated with grout returns and soil because of the compactness of the unit. Also, the grout used in Phase 1 is wax based, which is not the recommended grout for use in Phase 2.

Figures 12 and 13 illustrate the Phase I injection grouting machine and operator control station.

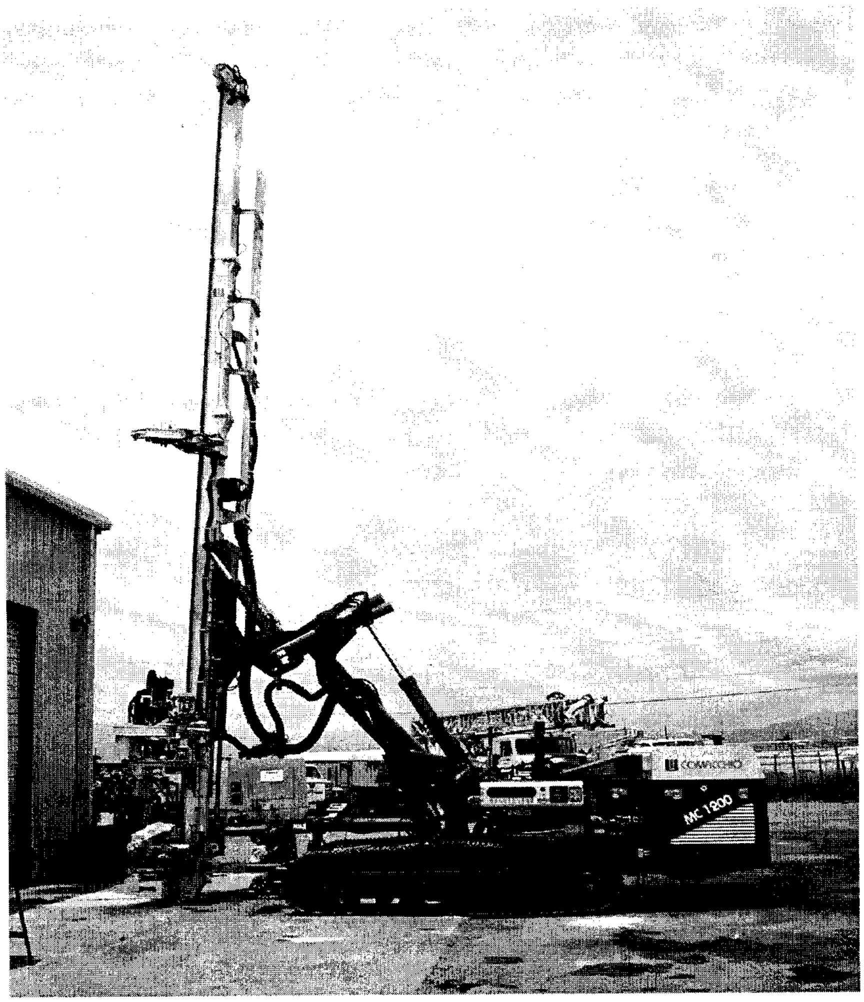


Figure 12. Phase I injection grouting machine.

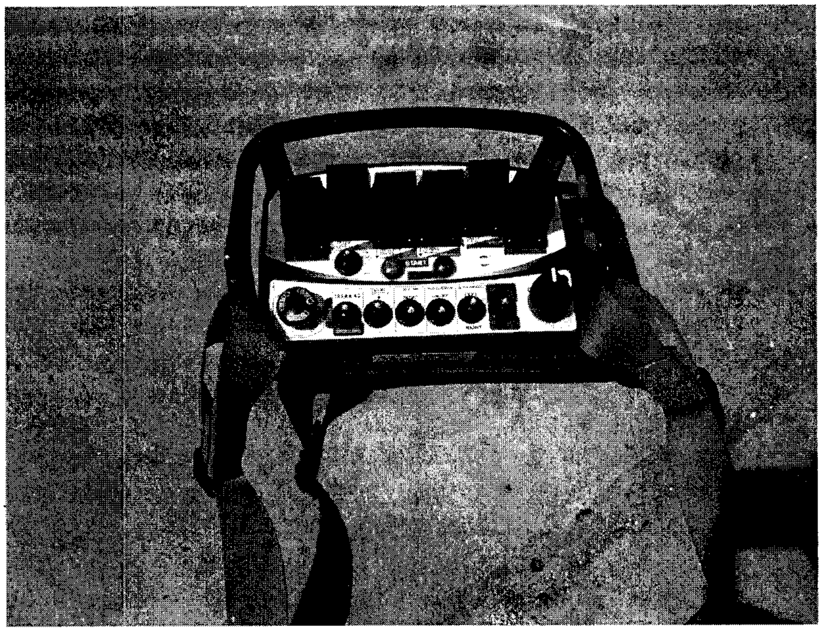


Figure 13. Phase I injection grouting operator control station.

For use of the Phase 1 type equipment in Phase 2, two paths could be taken:

- Use equipment similar to the Phase 1 equipment, but for use with cementitious grout, and modify the procedures and plans to reflect the use of cementitious grout,
- Review basis for the use of cementitious grout for Phase 2, and allow use of wax-based grout.

For the first path, use equipment similar to the Phase 1 equipment but for use with cementitious grout, it would be envisioned that some changes to the equipment would be needed and procedures rewritten. However, this type of equipment is routinely used for cementitious grouting. For the latter, if wax-based grout were allowable, and existing procedures and equipment would suffice, then potential benefits of reduced project cost could be realized, especially for FY-2005 limited scope stabilization. Out-year productivity needs may preclude the use of Phase 1 type equipment because of potential productivity limitations of the smaller equipment. Also, the cost difference between wax-based grout and the more economical grout may preclude this option for larger scale efforts.

The following provides a summary of technical, contamination control, and project issues for use of the Phase I type equipment for Phase II:

- Phase 1 equipment is sized and fabricated for use with a waxed-based grout. Phase II baseline uses a cementitious grout.
- The Phase 1 drill rig is compact close coupled to the track unit and locally or remotely-controlled through an operator station. This may be undesirable for Phase II operations, personnel may be too close to the drill string hole location.
- Phase I is a small scale localized effort, whereas Phase II out-year scope is a large-scale effort. In Phase I, large inefficiencies in production operations are tolerable. However, for Phase II out years, production efficiency must be maximized because of the scale of the project.

8. LESSONS LEARNED FROM PREVIOUS PROJECTS

Lessons learned from early sonic drill rig probe insertion, and Phase 1 beryllium block grouting projects indicate excessive times to penetrate a compacted soil hardpan layer from approximately 2.5 to 5 ft depth at some locations.

Soils are generally characterized as typical of the surrounding geology and include basaltic type soils moderately to heavily consolidated. Typical soil breakdown is approximately 37 wt% quartz, 48 wt% clay minerals, 10 wt% calcite, and 5 wt% minor constituents. The climate is high altitude (i.e., 5,000 ft) arid desert.

Drilling times for this hard layer of 5 to 6 minutes of total drill time of 8 minutes had been encountered early in the Phase 1 project. This extended drill time combined with the higher flow gearing of the Phase 1 high pressure pump (no gearing provided for trickle flow) resulted in excessive grout volumes returning early to the surface. The Phase 1 drill rig used a vibration/hammer with rotation capability. The probe insertion project used a sonic drill rig with rotation capability.

Good results were obtained by using a fluted bit with rotation and vibration or percussion assisted drilling. Percussion was used during the Phase 1 Project when necessary for additional penetration capability.

Figure 14 illustrates a modified drill tip with heavy fluted cutting edges that was used by the sonic drill rig in the probing effort. The Phase 1 beryllium block grouting project used a similar type bit with a 1/2-in. long flute.

Figure 14. Fluted drill bit.

9. RISKS

Table 4 provides a summary discussion of project risks with each alternative.

Table 4. Alternative risks.

Alternative	Advantages	Disadvantages
1	Commercially practicable Large commercial project base to draw from Many vendors technically and financially capable	Radioactive operations not in experience base of most vendors Jet grouting codes and standards development immature Entire operation somewhat complex with a number of steps required to be performed for each hole
2	Commercially practicable, based on other construction industry practice Simple with potentially fewer repetitive setup and operational steps Potential reduction in contamination control issues at the drill soil interface	Jet grouting project experience base minimal, some development required May not provide sufficient capability to meet radiological controls requirements for cleaning the drill string
3	Phase I procurement and operations experience base to draw from Similar procedures already used	May not provide adequate personnel contamination protection Different grout formulation, cementitious versus Waxfix™ present equipment and component modification needs, or change of Phase 2 baselining Savings on initial purchase costs may be dwarfed by cost increases because of modifications and production inefficiencies for larger Phase II out year project scope

10. CONCLUSIONS

The approach for injection grouting of contaminant waste zones for the formation of monolithic grouted masses, using a roto-percussion, rotary sonic drill, or rotary drill with fluted bit and injection grouting rig attached to a sufficiently large hydraulic excavator as depicted in Alternative 1, is considered a valid approach and commercially practicable. Standards development for hydraulic excavators is mature and covered under earth moving equipment of ISO. The jet grouting industry is considered mature; however, standards and regulatory environment development for jet grouting equipment is immature and follows the lead of the European standards development community. Vendor knowledge, trade secrets, and expert consultant help appear to be used to a great extent. Potential future procurements for jet grouting equipment should recognize the immature status of the standards and regulatory environment of the jet grouting industry and address relevant issues in the procurement.

Alternative 2 is also considered technically and commercially practical and may provide benefits of increased production do to reduced number of repetitive operational steps, and reduction in potential of contamination spread do to fewer components at the drill pipe soil interface. However, use of Alternative 2 methods for injection grouting operations would be considered newer technology with a reduced experience base, and with perhaps less flexibility in equipment. This alternative may require some development effort.

Alternative 3, use of equipment similar to Phase 1 equipment and methods, is considered technically feasible and may be cost effective for FY-2005.

11. RECOMMENDATIONS

This conceptual design effort recommends that the approach for single fluid injection grouting of contaminant waste zones for the formation of monolithic grouted masses, as well as foundation grouting using a roto-percussion, rotary sonic drill, or rotary drill with fluted bit and injection grouting rig attached to a sufficiently large hydraulic excavator, is a valid approach and commercially practicable. Alternative 1, using the drill rig attached to a linear mast, is the recommended approach and should provide sufficient similarities to commercial practices for competitive bidding.

This conceptual design recommends the allowance for use of used equipment based on vendor desires. This allowance should provide some means for potential bidders to reduce their financial risk.

This EDF also recommends further study of Alternative 2, using a mastless drill head and active hydraulic sensing and controls, provided funding is available.

12. REFERENCES

Barrow, J., Sonic Drilling Method and Apparatus, US Patent #5,562,169, October 8, 1996

Depth contour map of the Subsurface Disposal Area, INEEL Spatial Analysis map, sda_sediment_thickness_dl_v3.mxd, dated 8/9/2004

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EDF-5102, OU 7-13-14 In Situ Grouting Project Grout Delivery System

EDF-5135, OU 7-13-14 In Situ Grouting Project Grout Storage and Mixing

EDF-5155, OU 7-13-14 In Situ Grouting Project Operations, Maintenance, and Logistics

E-mail communications with E. Carter, Carter Technologies Company, Project Technical Consultant for Injection Grouting,

E-mail correspondence on reference hydraulic excavator standards, David Gamble, Manager Product Safety and Compliance, John Deere Dubuque Works, 7/22/2004.

Factory Mutual Data Sheet 7-40, Heavy Duty Mobile Equipment

INEEL/EXT-99-00739, Technical and Functional Requirements for the WAG 7 Drill String Enclosure

INEEL/EXT-01-00278, Evaluation Of In Situ Grouting for Operable Unit 7-13/14

ISO Standard 9244:1995, Earth-moving machinery—safety signs and hazard pictorials—General principles

MCP-540, Documenting the Safety Category of Structures, Systems and Components.

OSHA Regulations

Phase 1 ISG status e-mail, D. E. Crisp to D. Abbott, subject: Be ISG PROJECT MODIFICATIONS, soil hardpan issue and grout returns, 7/22/2004

Raivo, B. et al., Waste Description Information for Transuranically Contaminated Wastes Stored at the Idaho National Engineering Laboratory, INEL-95/0412, December 1995.

Responses to Expression of Interest, Integrated Hydraulic Excavator and High Pressure Grout Injection Machine, Federal Business Opportunities, Posted 5/11/04, Closed 5/26/04.

TFR-267, Requirements for the OU 7-13/14 In Situ Grouting Project (Customer, Project, and System)

Vendor Information, Parker Brinkerhoff, http://www.pbworld.com/news_events/publications/network/issue_40/40_10_PepeF_JetGroutingResearch.asp

Vendor Information, Caterpillar, www.cat.com

Vendor Information, Doofer Rock Drills, http://www.doofor.com/products/df751.htm

Vendor Information, Hayward Baker, http://www.haywardbaker.com/services/jet_grouting.htm

Vendor Information, Ingersoll Rand, http://www.ircmg.com/rockdrill/4066/gen_p1.htm

Vendor Information, International Construction Equipment (ICE), www.iceusa.com

Vendor Information, John Henry Co., http://www.johnhenryrockdrill.com/index.html, http://www.johnhenryrockdrill.com/action.html

Vendor Information, M. Meehan, Hercules Machinery Corp., www.hmc-us.com.

Vendor Information, Paul Eberhardt, Western Rubber and Mfg., www.westernrm.com,

Vendor Information, PACO, http://www.pacoequip.com/db_catalog.html?parent_id=145

Vendor Information, Precision Sampling http://www.precisionsampling.com/print-version.php

Vendor Information, Prosonic Corporation, http://www.prosoniccorp.com/sonicdrilling.html

Vendor Information, TRAMAC, http://www.tramac.com/rockdrills/drills.htm, http://www.tramac.com/whatsnew/article22.htm

Vendor Information, Dean Bennett Company, http://www.deanbennett.com/drill-stem-wipers.htm

13. APPENDIXES

Appendix A—Standards

Appendix B—GIS Preliminary Subsurface Disposal Area Data

Appendix C—Drawings

Appendix D—Excavator Information, Caterpillar Model 345B and Model 385

Appendix E—Auger Type Drill Rig Mounted On 90,000-lb Class Hydraulic Excavator

Appendix F—Injection Grouting Methods, Hayward Baker

Appendix G—High Pressure Swivel, Western Rubber and Manufacturing

Appendix H—Active Control of Hydraulic Control Circuits (HMC, MOVAC Auto Sensing II)

Appendix A

Standards

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Appendix A

Standards

TC 127

Earth-moving machinery

Secretariat:	ANSI
Secretary:	Mrs. Sara Desautels
Chair:	Mr. Dan Roley (USA) until end 2008
Scope:	

Standardization of nomenclature, use classification, ratings, technical requirements and test methods, safety requirements, operation, maintenance manual format for earth-moving and related machinery.

Total number of published ISO standards related to the TC and its SCs:	121
Number of published ISO standards under the direct responsibility of the TC 127 Secretariat:	none
Participating countries:	21
Observer countries:	19
Other ISO and IEC committees in liaison:	ISO TC 22/SC 3, TC 22/SC 5, TC 23, TC 23/SC 19, TC 31, TC 43/SC 1, TC 70, TC 96, TC 110, TC 131, TC 159, TC 195 ISO/IEC JTC 1/SC 32
International organizations in liaison:	CECE, EC, WCO

ISO technical programme:
(drafts and new work items under the direct responsibility of TC 127)
Business plan (PDF 96 KB)
Working area on ISOTC

Committee	Title
TC 127/WG 2	Worksite data controlled earth-moving operation *The convener can be reached through: JISC*
TC 127/WG 3	Joint SC 1-SC 2 WG : Visibility (ISO 5006-1 and ISO 5006-2) *The convener can be reached through: ANSI*
TC 127/SC 1	Test methods relating to machine performance
TC 127/SC 2	Safety requirements and human factors
TC 127/SC 3	Operation and maintenance
TC 127/SC 4	Commercial nomenclature, classification and rating

Joint working groups under the responsibility of another committee:

TC 23/SC 15/WG 2 Joint TC 23/SC 15-TC 127/SC 2 WG: Tip-over protection structure (TOPS) for compact excavators - Laboratory tests and performance requirements (Revision of ISO 12117)

Meeting calendar

* Information definite but meeting not yet formally convened
** Provisional

Month	Date	Location		Committee
April-May 2005		Beijing (China)	**	TC 127 & SCs

New Memo | Reply | Reply To All | Forward | Delete | Follow Up | Folder | Copy Into New | Chat | Tools

Lynn E Melander/MELALE/CC01/INEEL/US
07/22/2004 02:51 PM

To: Brian D Raivo/RAIVBD/CC01/INEEL/US@INEL
cc:
bcc:
Subject: Fw: Inquiry on the applicable standards for Hydraulic Excavators

See website below.
----- Forwarded by Lynn E Melander/MELALE/CC01/INEEL/US on 07/22/2004 02:50 PM -----

"Gamble David B" <GambleDavidB@johndeere.com>
07/22/2004 02:43 PM

To: melale@inel.gov
cc:
Subject: FW: Inquiry on the applicable standards for Hydraulic Excavators

David Gamble
Manager Product Safety & Compliance
Worldwide Construction & Forestry Div.
John Deere Dubuque Works
Email: GambleDavidB@JohnDeere.com
Phone: 563/589-6620
FAX: 563/589-5464

-----Original Message-----
From: Gamble David B
Sent: Thursday, July 22, 2004 3:41 PM
To: 'melale@inel.gov'
Subject: Inquiry on the applicable standards for Hydraulic Excavators

Dear Mr. Melander,
The applicable standards for hydraulic excavators are ISO standards under ISO Technical Committee 127 Earthmoving Machinery. Below is a web site that will list all the applicable standards for earthmoving machinery and these would needed to be sorted to those standards that apply to excavators as some apply to other machine forms. Below is a sorted list I have prepared for your reference; however, it may be out of date in terms of the most recent applicable standard editions and it was prepared for the North American market. Please contact me directly by phone or email if you need more assistance.

PS I hope John Deere excavators are being considered if there is a purchase opportunity.

<<CEDExc SafetyStds.doc>>
http://www.iso.ch/iso/en/CatalogueListPage.CatalogueList?ICS1=53&ICS2=100

Regards,
David Gamble
Manager Product Safety & Compliance
Worldwide Construction & Forestry Div.
John Deere Dubuque Works
Email: GambleDavidB@JohnDeere.com
Phone: 563/589-6620
FAX: 563/589-5464

EMM Excavator Regulations and Standards List - Draft
(John Deere Co. 7-2004)

29 CFR 1910 Regulations – General Industry

1910.95	Noise exposure max. 8 hours duration = 90 dBA slow response.
1910.147	Lockout and tagout procedures.
1910.212	Machinery guarding
1910.219 (c)	Mechanical power- transmission apparatus – shafting.
1910.219 (d)	Pulleys.
1910.219 (f)	Gears, sprockets, and chains.
1910.265 (c)(30)(iv)	Sawmills vehicles – overhead guard per ANSI B56.1
1910.265 (d)(1)(ii)(b)	Log handling equipment – lifting cylinders equipped with positive device for preventing uncontrolled lowering of load or forks due to hydraulic system failure.
1910.265 (d)(1)(ii)(c)	Lift arm limit switch required.
1910.265 (d)(1)(ii)(f)	Overhead protection required above operator.
1910.265 (d)(1)(ii)(g)	All mobile log handling machines equipped with headlights and backup lights.
1910.266 (d)(1)	Operating manual required.
1910.266 (d)(2)	Protective canopy required for operator station full width of cab & solid material. Upper rear portion of cab fully enclosed w/open mesh [1.75" openings]. Cab minimum vertical entry opening = 52" Safety glass or equivalent required with a metal mesh to achieve adequate protection.

29 CFR 1926 Regulations – Construction

1926.417	Lockout & tagout procedures
1926.600 (a)(5)	Safety glass or equivalent n cabs.
1926.601 (b)(1)	Service, emergency and parking brakes.
1926.601 (b)(2)	Two headlights, two taillights & brake lights.
1926.601 (b)(3)	Audible warning device at operator's station.
1926.601 (b)(4)	Reverse signal alarm above surround noise level or signal person.
1926.601 (b)(5)	Vehicle cabs equipped w/ windshield & powered wipers & defogging devices.
1926.601 (b)(13)	Rubber-tired motor vehicle equipment equipped with fenders or mud flaps.
1926.602 (a)(2)	Seat belts required for scrapers, loaders, crawler or wheel tractors, bulldozers, off-highway trucks, graders, agricultural & industrial tractors, and similar equipment. SAE J386 for construction equipment & SAE J333a for agricultural & light industrial tractors.
1926.602 (a)(2)(iii)	Seat belts not required for equipment w/o ROPS or canopy protection.
1926.602 (a)(6)	ROPS per Subpart W (1926.1000 – 1003).
1926.602 (a)(9)	Audible alarms required for bidirectional machines (rollers, compacters, front-end loaders, bulldozers and similar equipment)
1926.602 (b)(1)	Excavation equipment [per 1926.602 (a)] shall have seat belts.
1926.602 (c)(1)	Lifting & hauling equipment shall post rated capacity visible to operator.

EMM Excavator Regulations and Standards List - Draft
(John Deere Co. 7-2004)

1926.1000 (a)	ROPS required for scrapers, front-end loaders, rubber-tired dozers, wheel type agr & industrial tractors, crawlers & motor graders.
1926.1000 (c)(2)(ii)	ROPS vertical clearance of 52" from work deck at point of ingress or egress.
1926.1000 (e)	ROPS label includes manufacturer's name & address, model #, and machine identification number that ROPS was designed to fit.
1926.1001	ROPS performance requirements for scrapers, loaders, dozers, graders, and crawlers. (Ref. SAE J320a, J394, J395, J396)

30 CFR Part 56 Regulations – Mining

56.5050 (a)	Noise exposure limit = 90 dBA slow response over an 8 hour day.
56.14101	Minimum brake required to stop and hold equipment with typical load on maximum grade for self-propelled mobile equipment. Park brake capable of holding equipment on maximum grade it can travel
56.14103	Operator's station glass to be safety glass or equivalent.
56.14107	Guarding required for moving machine parts (exposed).
56.14130 (h)	Seat belt construction meets SAE J386.
56.14132 (a)	Horns & backup alarms required on self-propelled mobile equipment.
56.14132 (b)	Operator has obstructed view to the rear requires an automatic reverse-activated signal alarm, a spotter, a wheel mounted alarm bell alarm or discriminating alarm. Alarms shall be audible above surrounding noise levels.

30 CFR Part 77 Regulations – Mining

77.400	Mechanical equipment guarding requirements.
77.410	Automatic warning device required when rear view obstructed. Alarm must activate when equipment placed in reverse. Uses infrared light, ultrasonic waves, radar or other effective devices to detect objects or persons at rear of the equipment. Give audio and visual alarm inside the cab and outside the operator's compartment and audible above the surrounding noise. Strobe light can be substituted for night operation.
77.411	Compressed air and boiler constructed per ASME Pressure Vessel Code.
77.412	Compressed air system shall be equipped with automatic pressure relief values, pressure gages and drain valves.

West Virginia MSHA

Title 36 Series 27	40 psi glass for equipment working on coal stockpile applications.

British Columbia Occupational Health & Safety Regulations (296/97) – General Hazard Requirements

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Part 7 – Noise, Vibration, Radiation and Temperature	
7.2	Exposure limits – 85 dBA Lex (1 Pa^2 h) daily exposure & 135 dBA peak sound level.
7.25	Evaluation of vibration – whole body according to ISO 2631 Part 1 "Evaluation of Human Exposure to Whole-body Vibration"
7.26	Equipment selection & use – equipment that meets the guidelines must be used in preference to equipment, which produces higher levels of vibration.
7.27	Labels – equipment which produces levels of vibration above recommended guidelines must be labeled to identify the hazard.
Part 16 – Mobile Equipment	
16.8	Warning signal device – mobile equipment in which the operator cannot directly or by mirror or other effective device see immediately behind the machine must have an automatic audible warning device. The device must (1) activate whenever equipment controls are positioned to move the equipment in reverse, and (2) is audible above the ambient noise level. (Alternatives include a signal person)
16.9	Lights – that meet the requirements of SAE J1029 "Lighting & Marking of Construction and Industrial Machinery"
16.10	Rear view mirrors – must have a mirror or mirrors. Rear view mirrors are not required if the equipment makes the use of mirrors impracticable.
16.11	Window standards – safety glazing meeting ANSI Z26.1-1990 "Safety Glazing Materials for Glazing Motor Vehicles & Motor Vehicle Equipment Operating on Land Highways – Safety Code"
16.13	Braking requirements – SAE J1473, J1026, J1178, J1472, J/ISO 11512, J/ISO 11512, and ASME B56.6.
16.14	Supplementary steering – meeting SAE J1511 and ISO 5010.
[16.16]	Safe starting – equipment protected from engine starter engagement when coupled to the wheels or track.
[16.17]	Escape from a cab – mobile equipment manufactured after January 1, 2000 must have alternate means of escape that: (1) is clearly marked inside & outside; (2) can be opened from either inside or outside without the use of tools; (3) maximum opening force of 135 N (30#); and (4) has minimum opening size requirements [65 cm diameter, 60 cm square, 47 cm x 65 cm rectangle].
[16.18]	Controls – hydraulic log loaders, hydraulic excavators and hoe chucking machines must meet SAE J1177
[16.21]	Guards – must meet the applicable standards WCB Standard – G601-609, SAE J231, J1043, ISO 3449, J1084, J1356
[16.22]	Rollover protective structures – meet the requirements of ISO 3471 or SAE J1040.
[16.32]	Seat belt provisions according to SAE J386.

EMM Excavator Regulations and Standards List - Draft
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ISO Standards	
ISO 1585	Engine test code
ISO 2631	Guide for evaluation of human exposure to whole-body vibration
ISO 2860	EMM – Minimum access dimensions
ISO 2867	EMM – Access Systems
ISO 3164	EMM – Lab evaluations of ROPS & FOPS – specification for deflection-limiting volume
ISO 3411-1	EMM – Minimum operator space envelope
ISO 3449	EMM – FOPS – lab tests and performance requirements
ISO 3450	EMM-Braking systems of rubber-tired machines – Systems & performance requirements & test procedures
ISO 3457	EMM – Guards – Definitions & requirements
ISO 3461-1	Graphical symbols for use on equipment
ISO 3471	EMM – ROPS – lab tests & performance requirements
ISO 3600	Tractors & machinery for agr & forestry – Operator manuals & technical publications – presentation
ISO 3795	Road vehicles, & tractors and machinery for agriculture & forestry – Determination of burning behavior of interior materials.
ISO 3864-3	Safety colors & safety signs – product safety labels
ISO 4254-1	Forestry – Technical means for ensuring safety
ISO 4254- 4	Forestry winches
ISO 4510	Hand tools for maintenance & adjustment work
ISO 5005	EMM - Method of locating Center of Gravity
ISO 5006-1	EMM – Operator's field of view – Part 1: Test method
ISO 5006-2	EMM – Part 2: Evaluation method
ISO 5006-3	EMM – Part 3: Criteria
ISO 5010	EMM – Rubber-tyred machines – Steering requirements
ISO 5131	Agricultural Tractors & Forestry – Measurement of Noise at Operator's Position.
ISO 5353	EMM – Seat index point
ISO 5596	Accumulators
ISO 5805	Mechanical vibration & shock – Human exposure – Vocabulary
ISO 6011	EMM – Visual display of machine operation functions
ISO 6012	EMM – Service instrumentation
ISO 6014	EMM – Determination of ground speed
ISO 6015	EMM – Hydraulic excavators –Methods of determining tool forces
ISO 6016	EMM – Methods of measuring the masses of whole machines, their equipment and components
ISO 6165	EMM – Basic types – Vocabulary
ISO 6302	EMM - Drain, fill & level plugs
ISO 6385	Ergonomic principles in the design of work systems
ISO 6393	EMM – Acoustics – Measurement of exterior noise emitted by earthmoving equipment -Stationary test conditions
ISO 6394	EMM -Acoustics – Measurement at the operator's position of noise emitted by earthmoving machinery – Stationary test conditions

EMM Excavator Regulations and Standards List - Draft
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ISO 6395	EMM -Acoustics – Measurement of exterior noise emitted by machine – dynamic test conditions
ISO 6396	EMM -Acoustics – Measurement at operator's position of noise emitted by machinery – Dynamic test conditions
ISO 6405	EMM – Symbols – Operator
ISO 6405-2	EMM – Symbols for controls & displays Part 2: Special symbols.
ISO 6682	EMM –Zones of comfort & reach for controls.
ISO 6683	EMM – Seat belts & seat belt anchorages
ISO 6687	Forestry winch performance
ISO 6746-1	EMM – Definitions of dimensions & symbols – Base machine
ISO 6746-2	EMM – Definitions of dimensions & symbols – Equipment
ISO 6749	EMM – Preservation & storage
ISO 6750	EMM – Operation & maintenance Format
ISO 7095	
ISO 7096	EMM – Lab evaluation of operator seat vibration
ISO 7135	EMM – Hydraulic excavators – Terminology & commercial specifications.
ISO 7250-1	Basic human body measurements for technological design.
J/ISO 7451	EMM – Hydraulic Excavators – Hoe type buckets – volumetric rating.
ISO 7457	EMM – Determining of turning dimensions of wheeled machines
ISO 7464	EMM – Method of test for the measurement of drawbar pull
ISO 7546	EMM – Loader & front loading excavator buckets – Volumetric rating
ISO 7574-1	Acoustics – Statistical methods
ISO 8082	Forestry – ROPS – Lab tests & performance Requirements
ISO 8083	Forestry – FOPS – lab tests & performance requirements
ISO 8084	Forestry – OPS – Lab tests and performance Requirements
ISO 8152	EMM – Operation & maintenance – Training of mechanics
ISO/DIS 8178-9	Reciprocating internal combustion engines – Exhaust emission
ISO 8643	EMM – Hyd excavator & backhoe loader boom lowering control device.
ISO 8925	EMM – Diagnostic port sizes & accessibility.
ISO 8927	EMM – Def of terms concerning machine available & reliability
ISO 9244	EMM - Safety signs and hazard pictorials
ISO 9245	EMM - Machine productivity – vocabulary symbols & units
ISO 9246	EMM - Volumetric rating – dozer blades
ISO 9247	EMM - Electrical wires & cables: Principles of identification & marking
ISO 9248	EMM – Units
ISO 9249	EMM – Engine Test Code
ISO 9250-1	EMM - Multilingual list of equivalent terms
ISO 9533	EMM - Forward & reverse warning devices – audible alarms & sound test methods.
ISO 10261	EMM - Product identification numbering system

EMM Excavator Regulations and Standards List - Draft
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ISO 10262	EMM - Hydraulic Excavators-Lab tests & performance requirements for operator protective guards
ISO 10263	EMM - Operator environment
ISO 10264	EMM - Key-locked starting systems
ISO 10265	EMM - Performance Requirements & test procedures for braking systems (crawlers)
ISO 10266	EMM - Determination of slope limits for machine fluid systems operation-static test method
ISO 10532	EMM – Machine mounted retrieval device
ISO 10533	EMM – Lift arm support device
ISO 10567	EMM - Hydraulic excavators – lift capacity
ISO 10968	EMM - Operator's controls
ISO 11112	EMM - Operator's seat – dimensions & requirements
ISO 11169	Forestry brakes – wheeled machines
ISO 11512	Forestry brakes – tracked machines
J/ISO 11684	Agr & Forestry – Safety signs & Hazard pictorials
ISO 11850	Forestry – Self-propelled machinery – safety requirements
ISO 11862	EMM - Electrical connector for auxiliary starting aids
ISO 12117	EMM -TOPS for compact excavators – Lab tests & perf requirements
ISO 12508	EMM - Operator station & maintenance area – Bluntness of edges
ISO 12509	EMM - Lighting, signaling & marking lights, & reflex-reflector devices
ISO 12510	EMM - Operation & maintenance – Maintainability guidelines
ISO 12511	EMM - Hour meters
ISO 13458	EMM – Operating modes for determination of vibration
ISO 13564	
ISO 13677	EMM - Excavators – Performance testing of swing brakes
ISO 13766	EMM - Electromagnetic Compatibility
ISO 14401-1	EMM - Field of vision of surveillance & rear-view mirrors – Part 1: Test method
ISO 14401-2	EMM - Field of vision of surveillance & rear-view mirrors – Part 2: Performance criteria
ISO 15219	EMM - Cable excavators – terminology & commercial specs
ISO 15817	EMM - Safety requirements for remote operator control
ISO 15818	EMM - Lifting & tying-down devices
ISO 15832	EMM - Driving assistance & control equipment embarked on rollers – terminology & commercial classification
ISO 15998	EMM - Machine-work management systems (MWMS) using electronic components – Requirements and tests
ISO 16001	EMM - Hazard Detection, visual aids and warning systems – Performance requirements & tests

Research & Development at PB

Recent Advances Are Changing Design And Construction

Jet Grouting Research and Applications

By **Frank Pepe**, New York, NY 212-465-5215, pepe@pbworld.com

One of the first lessons an engineer learns is that a key to success is to continue to learn about new technologies. Recognizing this fact and the potential benefits of new technologies, PB is funding research on jet grouting—a powerful ground improvement technique. This article discusses some aspects of the research and jet grouting application.

Ground improvement is one of the most interesting and innovative practice areas within geotechnical engineering. It includes a wide range of technologies that modify the in situ properties of a soil or rock deposit by increasing its strength, reducing its compressibility or decreasing its permeability so that the deposit is suitable for a design purpose. One such technology, jet grouting, is receiving considerable attention.

Jet grouting is a soil grouting method that uses a very high pressure of 34,500 kPa to 55,000 kPa (5,000 to 8,000 psi) to inject a cutting and ground cementing fluid into a soil deposit. The high pressure fluid, which can be the cementing agent, cuts and mixes with the natural soil and forms a cemented soil element (Figure 1). The method is basically an erosion/replacement process that removes a portion of the soil particles and replaces them with a mixture of soil and cement grout that has an increased strength and low permeability when hardened. The most common elements produced by the jet grouting, either cylindrical columns or panels, can be combined to form stabilized blocks and walls of material that can be part of a construction project.

The use of jet grouting has increased tremendously in much of the world since the late 1970s and in the U.S. since the late 1980s. This growth is due to the increasing awareness of the benefits that jet grouting provides and the strong marketing efforts made by specialty contractors. The system is very flexible and can be used to treat a wider range of soils than any other grouting system (Figure 2).

PB has used jet grouting on the Baltimore Metro in Maryland, the Cairo Metro in Egypt, and on the MARTA system in Atlanta, Georgia, and is currently using it on the 63rd Street Tunnel Connection in New York City and on the Central Artery/Tunnel project in

Change the Design Or Change the Geology

An engineer working on an underground project can adjust either the design to the geology or the geology to the design. Historically, we have done the former more than the latter, but as our projects become more complex and the sites more challenging, it is becoming more and more necessary that we adjust the geology. Jet grouting is a major tool for making such adjustments and Frank is leading the charge. Clearly, his work will be of great value in improving our knowledge in order to make applications of jet grouting.

Boston, Massachusetts. (See also "Unique Ground Improvement Designs for Seismic Retrofit of Posey and Webster Street Tubes" by Youssef Hashash, etal, in this issue. For previous PB Network articles describing the use of jet grouting on the Baltimore, Cairo, CA/T and other projects, see the Fall '96 issue on Slurry Walls.)

James E. Monsees
Technical Director,
Underground Structures

Research Stems from William Barclay Parsons Fellowship Program

Recognizing the potential applications of jet grouting for our industry, PB is funding an R&D project to study the use of jet grouting for foundation and underground construction and develop guidelines that engineers can use to develop specifications and quality control and testing requirements for a jet grouting project. This project was initiated when I was selected as a finalist for the William Barclay Parsons Fellowship Program in 1994.

The research has been applied to a number of projects, including my participation on a task force to investigate the causes of severe building movements adjacent to a jet grouting project. This work and participation in a significant number of other jet grouting projects has delayed the completion of the research report, but has provided an ideal source of practical information. Such information would not be available from any other source.

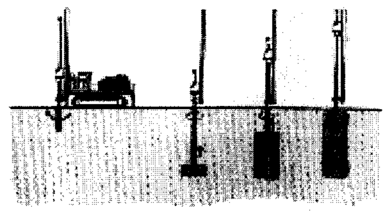

Figure 1: Jet grouting procedure.

Methods of Jet Grouting

There are three basic jet grouting systems: single, double and triple fluid. The basic principle of each is the same, as described above. The main differences are in the number and types of fluids injected through the grouting rod and operating factors such as fluid flow rates, injection pressures, rod rotation and withdrawal rates (see Table 1 and Figure 3).

As Table 1 shows, the single and double fluid systems use cement grout pumped at high pressure and flow rates to cut and mix the soil to form the jet grouted elements. The introduction of air in the double fluid system concentrates the grout cutting jet by shielding the high pressure cement grout conically, thereby increasing the cutting distance. The triple fluid system uses a combination of high pressure water shielded in a cone of air to cut and displace soil to the top of the hole while cement grout is injected below the cutting jet and mixed with disturbed soil.

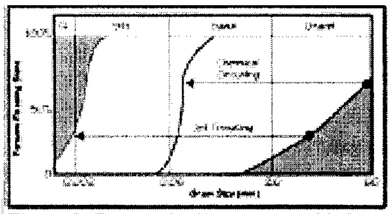

Figure 2: Range of soil types treatable by chemical and jet grouting (adapted from Welsh, 1992).

Table 1: Jet grouting systems

[illegible]	[illegible]	[illegible]	[illegible]
Single Fluid	Grout	30,000-58,000	60-300
Double Fluid	Grout Compressed Air	30,000-55,000 700-1,000	100-350 1,000-3,000
Triple Fluid	Grout Compressed Air Water	1,000-4,000 700-1,000 30,000-50,000	120-200 1,000-3,000 20-100

The Stages of a Typical Jet Grouting Project

The typical jet grouting project generally consists of four stages:

- Planning and conceptual development
- Design and specification
- Test program and field trial
- Production grouting and QA/QC testing

Planning and Conceptual Development. At this stage, the engineer must answer a key question, "Can jet grouting be used for the intended application and soil condition?" This question is very important because jet grouting has limitations and cannot be used for every project. Its use in the wrong application or soil conditions can cause significant problems.

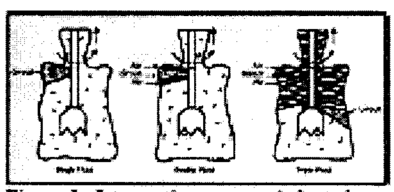

Figure 3: Jet grouting systems (adapted from Welsh, 1992).

Design and Specification. It is critical that the engineer collect the necessary design information and perform geotechnical and structural analyses to define design parameters and performance criteria for the jet grouting. Contract documents for jet grouting are generally performance-type documents. These documents must be carefully prepared so that the jet grouting application will perform adequately as part of the design and the contractor clearly understands the project requirements.

A critical element of this stage is the development of a complete set of specifications that clearly define the design, testing and quality control requirements for the jet grouting application, and the method of payment. The development of the design, testing and quality control requirements should generally be done by the engineer. The jet grouting techniques and detailed procedure development are best left to the contractors who specialize in the technique and have experience and expertise in its performance.

Test Program and Field Trial. At the present time, there is no standard procedure that can be used to design the jet grouting. Correlations that define gross properties of jet grouted soils exist, but development of a simple, universally accepted design approach is precluded by the variations in techniques used by contractors and the variability of the soil. Prior to any production grouting, a test program and field trial must be conducted on site using the contractor's proposed equipment and techniques to establish the procedures and grouting parameters for use in the production grouting.

The test program must include quality control testing and adequate monitoring to validate that the procedures and techniques used will provide the design requirements and satisfy the assumptions made during design. It is critical that the engineer plan and specify the testing program and acceptance criteria so that the design is verified and performance of the jet grouting system is adequate.

Production Grouting and QA/QC Testing. Quality control and assurance procedures and inspection must be provided to ensure that grouting procedures and parameters developed from the test program are followed. This is one of the most critical phases of the project and must be conducted by qualified, experienced representatives from both the contracting and engineering firms. Quality control tests must be conducted on production columns to confirm that adequate performance has been achieved.

Jet Grouting Standard:

Jet grouting can be used in a wide range of soils and the equipment used is easily adaptable to various site conditions. Its use for a variety of applications, especially in Japan and Europe, has led to the development of European Jet Grouting Standards. These standards, which are essential for the successful use and growth of jet grouting technology, address the key issues for the execution, testing and monitoring of jet grouting applications. At this time, the European Jet Grouting Standards are being finalized by the European Committee for Standardization (CEN) for use by all CEN members.

The development of similar standards in the U.S. has lagged behind the European experience. This delay is due partly to the relatively new acceptance and use of jet grouting in the U.S. Without reliable and adequate design, specification, testing !nd monitoring standards, however, engineers who want to use the technique are forced to "reinvent the wheel" and learn the same lessons that other engineers have learned. The lack of standards leads to problems that can result in poor performance of the jet grouting or worse. Because of the high pressures used in jet grouting, the consequence of mistakes can be severe, especially when the technique is used in urban construction.

Conclusion

PB's research on jet grouting is attempting to identify the requirements for jet grouting execution and provide guidance to engineers who develop jet grouting contract documents and monitor of field operations. A report that is being prepared will present specification guidelines, testing recommendations and inspection quality control checklists and guidelines. The report will be available to PB engineers and our peers and will add, it is hoped, to the knowledge and successful application of jet grouting. **R&D**

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